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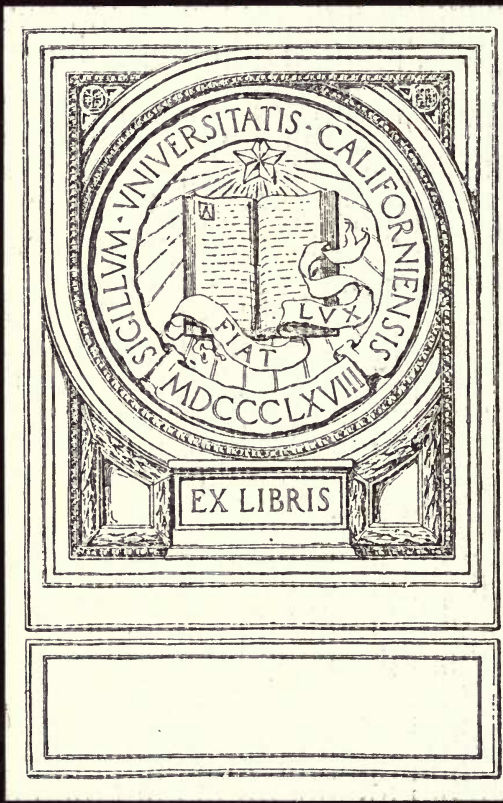
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# PRACTICAL SHOP MECHANICS

AND

# MATHEMATICS

BY

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Dedicated

TO THE

AMBITIOUS WORKMAN

423686.

# PREFACE

THE following notes are the results of efforts to secure for the mechanic and the student of the trades a concise and clear arrangement of those simpler branches of applied mechanics, and the mathematics directly related to them, that pertain to actual shop conditions.

The notes are based upon teaching experience among these tradesmen and upon shop practice covering a period of nine years. All notes have been in use in evening schools and in technical and trade schools, and have been thoroughly tried out with a very gratifying success.

Every effort has been made to convey a correct understanding to the student, and in all cases rules and formulas are illustrated by practical examples, the solutions of which are worked out in detail.

By this means it is believed that the mystifying element that usually surrounds shop mechanics has been eliminated, and notes have been formulated that are usable at all times and are really of value to the ambitious student and tradesman.

JAMES F. JOHNSON.

BRIDGEPORT, CONN.,
February, 1915.

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# PRACTICAL SHOP MECHANICS AND MATHEMATICS

## CHAPTER I

### MATERIALS

**1. Iron.** Iron is reduced from its ore in a blast furnace into a product called *pig iron*. This product contains a chemical element, carbon, which is mixed with the iron, giving it a grayish appearance, the result being gray iron; or it may be in combination with the iron, giving it a whitish appearance when broken, the result being white iron.

The gray iron is used in foundry practice and gives good castings. White iron is brittle and hard, and is used for making wrought iron and steel.

Castings are made by melting pig iron and scrap in a cupola and pouring the resulting molten iron into sand or loam moulds which in turn were built up from patterns of the piece to be moulded.

Should the iron in the mould cool quickly, there will be a tendency to chill the casting, making it very hard and similar to white iron. This making of chilled castings is sometimes accomplished by chilling the moulds with circulating water. In such a case, part of the mould to be

chilled is of iron instead of sand. Car wheels and cast iron press rolls are types of chilled castings.

**2. Properties of Cast Iron.** Cast iron is not very ductile, but is strong under compression and weak under tension. It is quite brittle, and when broken, the surface appears to be crystalline, resembling grains of sand closely pressed together.

The average ultimate strength of cast iron is referred to as about 15,000 lbs. per square inch when in tension, and 80,000 lbs. per square inch when in compression. One-sixth of these figures should be considered the average working strength when the load on the cast iron parts is steady. If the parts are subjected to suddenly varying loads or shocks, as in machinery, one-twentieth should be used.

**3. Wrought Iron.** Wrought iron is iron that has been made as nearly pure as possible, being so worked in process of making as to become fibrous in structure instead of crystalline. It is made from pig iron by a preliminary process which tends to refine it by removing much of its impurities. After this it is put into a *puddling furnace* and further worked, this time into a pasty mass, in which condition it leaves the puddling furnace to be further squeezed and hammered, ridding it of slag and making it into a more compact mass.

After this process it is made up into what are called *puddle bars* or *billets.*

The iron may be further improved in quality by reheating and hammering as before, each process tending to improve it. After its final process it is rolled into plates and bars ready for the market.

**4. Properties of Wrought Iron.** Wrought iron is ductile and fibrous. It can easily be worked into various shapes, possesses malleability, and can be welded.

Wrought iron, while showing an ultimate tensile strength of 48,000 lbs. per square inch, has a compressive strength of about 45,000 lbs. per square inch. Where the load on the wrought iron is steady, about one-quarter of these figures is used for the working load, while about one-twelfth is used where the load varies suddenly or the piece is subjected to shocks.

**5. Steel.** Steel is iron made as pure as possible with the addition of a small amount of carbon. In the *Bessemer* and *"open hearth" processes* the carbon is partly burned out of pig iron; in the *crucible process* carbon is added to wrought iron. The amount of carbon in the steel divides it into classes known as mild steel, hard steel, low carbon steel, high carbon steel, etc.

*Mild steel* resembles wrought iron and contains a small amount of carbon. It is used frequently in machine work, and is referred to as low carbon steel.

*Hard steel* is a fine quality of high carbon steel made by baking wrought iron for several days in contact with charcoal. It is the kind of steel used in high speed steel tools. The carbon in the charcoal enters the iron during the process of manufacture and the resulting steel is known as *blister steel.*

By stopping the process at different stages, a steel suited for different manufacturing purposes may be obtained. This steel is used for arbors, tools, steel saws, springs, wrenches and cutlery.

*Cast steel*, called crucible steel, was formerly obtained from the blister steel by melting it in crucibles. It is made more recently by remelting in an air-tight crucible pieces of wrought iron and other materials containing the proper amount of carbon.

**6. The Hardening and Tempering of Steel.** Steel may

be hardened by dipping it while hot into water so as to cool it suddenly. This makes it hard and brittle. By reheating it looses its brittleness and some of its hardness, and is said to be tempered. The temperature at which steel acquires a temper best suited for its different purposes is found in practice by the color which comes to the surface upon reheating.

The following tempering color chart with temperatures may give a clearer idea of the great importance of the tempering and care needed in treating steel:

| Tools. | Color. | Average Temperature. |
|---|---|---|
| Lathe tools<br>Cut-off tools<br>Counterbores<br>Milling cutters<br>Reamers<br>Planer tools<br>Forming tools | Light straw<br>or<br>Pale yellow | 400° F.<br>to<br>430° F. |
| Twist drills<br>Centering tools<br>Fly cutters<br>Countersinks | Straw yellow | 460° F. |
| Chisels<br>Knurls<br>Taps | Brownish yellow | 490° F. |
| Thread dies | Spotted red brown | 490° F. |
| Saws | Dark blue | 500° F. |

To temper by color requires considerable experience and is at best doubtful. It is a more advisable method to draw

the temper in an oil bath heated to the desired temperature.

**7. Malleable Iron.** *Malleable castinys*, sometimes called malleable iron, are made from ordinary cast-iron castings by heating them for several days in annealing pots in contact with some substance that will remove the carbon in the iron. This process makes the cast iron more like steel

**8. Case Hardening.** The process by which a surface of high carbon steel is given to low carbon iron is called *case hardening*. The process is accomplished by heating the article in contact with some substance such as charcoal, granulated bone, or cyanide of potassium, which will give the carbon to the iron.

A common method of case hardening is to pack the pieces in iron boxes and cover them with granulated bone, the pieces to be carbonized being separated so that the bone can get well around them. After sealing the cover of the box in crucible clay it is heated in a furnace to about 1600° F. The longer the box remains in the furnace the deeper will be the carbonized surface. The grade of hardening may be conditioned by reheating and quenching, using either water or oil.

**9. Copper.** This metal is produced by reduction from its ores. It is used in sheets, bars and wires, is strong and malleable and very ductile. Copper may also be forged at a moderate red heat, and each time has its strength improved by such process.

It is a good conductor of electricity and heat, and resists corrosion by water or air.

**10. Tin.** Tin is obtained from its ore, *tin stone*. Its strength and ductility are low, but it is very malleable, being easily rolled or hammered into sheets, which is known

as *tin foil*. It becomes very brittle when heated near its melting point. Tin is much used for coating other metals to protect them from rust and wearing out. Thin iron plates treated this way give the commercial *tin plate* so commonly referred to as tin.

**11. Phosphorus Bronze.** This material is an alloy consisting chiefly of copper with some tin and phosphorous. It may be obtained in rods, sheets, wires, or castings. It will not corrode, and because of the low frictional resistance offered is well fitted for bearings in high speed machinery.

**12. Babbitt Metal.** Babbitt metal consists of tin in composition with a very small amount of copper and antimony. It can easily be melted and is used frequently for lining bearings.

**13. Zinc.** This metal is obtained from zinc ore. It is brittle at ordinary temperatures, but is malleable and can be rolled into sheets at medium temperatures. Its principal use is for coating iron plates to protect them from rust and corrosion. Thin iron plates treated in this manner are known as *galvanized iron*.

**14. Aluminum.** Aluminum resembles zinc in color and hardness. It weighs less than one-tenth of a pound per cubic inch but shows an ultimate tensile strength of 15,000 lbs. per square inch, which is about one-third that of wrought iron. The metal may be rolled into sheets and can be drawn, forged or cast.

**15. Lead.** The metal is obtained from lead ore. It is soft and very heavy, is low in tensile strength and makes poor castings. It is easily made into sheets or pipes. Lead pipes are sometimes lined with tin to protect them.

**16. Concrete.** Concrete is made of a mixture of cement, sand and crushed stone arranged in such proportions as from experience and tests have been proven to be best

suited to different cases. For example, a mixture made up of one portion of cement, two of sand and three of crushed stone gives a suitable concrete for highway work, walks, roofs and fence posts. A mixture of the proportions 1, 2, and 4 would be more suitable for reinforced floors, beams and columns, or construction subjected to vibrations, while a mixture of the proportions 1, 3 and 5 would be proper for concrete footings, basement walls and foundations. These mixtures are sometimes reinforced by iron lattice work, iron bars or rods, and upon drying become thoroughly cemented into one mass, which hardens as it ages and is not affected by water. The compressive strength of concrete varies from 1000 to 2000 lbs. per square inch, according to its age.

Concrete is usually surfaced with a mortar made of sand and cement in proportions from 1 to $1\frac{1}{2}$ up to 1 to 3, depending on what the surfacing is to be used for and upon what base it is to be put.

Of late concrete has become an important factor in building. Its high compressive strength and durability, together with its moderate cost, ease of construction and fire-proofing qualities, have brought it into wide use. The readiness with which it can be adapted to different constructions through use of forms has brought it into the decorative field and broadened its use in construction work. These forms are usually made of wood, but sometimes of metal, and after the concrete which has been poured into them is thoroughly set, they can be removed, leaving the concrete mass moulded according to the form used.

**17. Timber.** Lumber is still the universal building material. Its extensive use in all branches of building and construction work, and the readiness with which it can be handled and worked, still bring it into active use

regardless of its many substitutes. Even in larger construction work there are many cases where iron or concrete are unsuitable and where wood is the only material which can be used.

The strength of timber is quite variable and is effected considerably by defective growth and seasoning. Knots, sapwood, season-cracks and decay are sources as well as signs of weakness. Because of this, timber used in construction should be as free as possible from such defects.

The working strength of spruce ranges from 800 to 1200 lbs. per square inch. Yellow pine varies between 1000 and 1200 lbs. per square inch, it being strongest in compression, while white pine ranges from 700 to 1300 lbs. per square inch. Among the other woods, oak shows a working strength of 1100 lbs. per square inch, hemlock 800, and chestnut 1000 lbs. per square inch.

Aside from its medium strength as a building material, timber is further weakened by the practice of notching and cutting as employed in framing. This method of framing materially affects the strength of the timber and experiments have shown a reduction of as much as 50 per cent in the bearing power of timber so notched.

## CHAPTER II

## MEASURES AND WEIGHTS. MEASURING INSTRUMENTS

**18. Linear Measure.**

12 inches (abbreviated in. or ″) = 1 foot (abbreviated ft. or ′).

3 ft. = 1 yard (abbreviated yd.).

5280 ft. or 1760 yds. = 1 mile (abbreviated mi.) = 880 fathoms.

**19. Comparison of English and Metric Standards.**

1 kilometer or 1000 meters = about $\frac{5}{8}$ of a mile.

1 meter = 39.37 inches, or about $3\frac{1}{4}$ feet.

1 decimeter = $\frac{1}{10}$ part of a meter = 3.937 inches.

1 centimeter = $\frac{1}{100}$ part of a meter = 0.3937 inches.

1 millimeter = $\frac{1}{1000}$ part of a meter = 0.03937 inches.

1 mile = 1.61 kilometers = 1610 meters.

1 yard = 0.914 meter = 91.4 centimeters.

1 foot = 0.305 meter = 30.5 centimeters.

1 inch = 0.0254 meter = 2.54 centimeters = 25.4 millimeters.

**20. Decimal Equivalents of Fractional Parts of One Inch.**

| | | | | |
|---|---|---|---|---|
| $\frac{1}{64}$ .015625 | $\frac{7}{32}$ .218750 | $\frac{27}{64}$ .421875 | $\frac{5}{8}$ .625000 | $\frac{53}{64}$ .828125 |
| $\frac{1}{32}$ .031250 | $\frac{15}{64}$ .234375 | $\frac{7}{16}$ .437500 | $\frac{41}{64}$ .640625 | $\frac{27}{32}$ .843750 |
| $\frac{3}{64}$ .046875 | $\frac{1}{4}$ .250000 | $\frac{29}{64}$ .453125 | $\frac{21}{32}$ .656250 | $\frac{55}{64}$ .859375 |
| $\frac{1}{16}$ .062500 | $\frac{17}{64}$ .265625 | $\frac{15}{32}$ .468750 | $\frac{43}{64}$ .671875 | $\frac{7}{8}$ .875000 |
| $\frac{5}{64}$ .078125 | $\frac{9}{32}$ .281250 | $\frac{31}{64}$ .484375 | $\frac{11}{16}$ .687500 | $\frac{57}{64}$ .890625 |
| $\frac{3}{32}$ .093750 | $\frac{19}{64}$ .296875 | $\frac{1}{2}$ .500000 | $\frac{45}{64}$ .703125 | $\frac{29}{32}$ .906250 |
| $\frac{7}{64}$ .109375 | $\frac{5}{16}$ .312500 | $\frac{33}{64}$ .515625 | $\frac{23}{32}$ .718750 | $\frac{59}{64}$ .921875 |
| $\frac{1}{8}$. 125000 | $\frac{21}{64}$ .328125 | $\frac{17}{32}$ .531250 | $\frac{47}{64}$ .734375 | $\frac{15}{16}$ .937500 |
| $\frac{9}{64}$ .140625 | $\frac{11}{32}$ .343750 | $\frac{35}{64}$ .546875 | $\frac{3}{4}$ .750000 | $\frac{61}{64}$ .953125 |
| $\frac{5}{32}$ .156250 | $\frac{23}{64}$ .359375 | $\frac{9}{16}$ .562500 | $\frac{49}{64}$ .765625 | $\frac{31}{32}$ .968750 |
| $\frac{11}{64}$ .171875 | $\frac{3}{8}$ .375000 | $\frac{37}{64}$ .578125 | $\frac{25}{32}$ .781250 | $\frac{63}{64}$ .984375 |
| $\frac{3}{16}$ .187500 | $\frac{25}{64}$ .390625 | $\frac{19}{32}$ .593750 | $\frac{51}{64}$ .796875 | 1 1.000 |
| $\frac{13}{64}$ .203125 | $\frac{13}{32}$ .406250 | $\frac{39}{64}$ .609375 | $\frac{13}{16}$ .812500 | |

### PROBLEMS

1. How many bolts $5\frac{3}{4}''$ long (over all) can be cut from a bar 6 ft. long, allowing $\frac{1}{8}''$ for cutting off and finishing up each end of each bolt?

2. It is required to make 10 W. I. angle braces by bending up strip metal, one side of brace measuring $1\frac{1}{2}''$, the other side at right angle to it measuring $2''$. How long a strip is needed, allowing $\frac{1}{8}''$ for saw cut and finishing on each piece?

3. A machinist finds that he has 6 pieces of $\frac{3}{4}''$ round stock, measuring respectively 3 ft. $7''$, 4 ft. $9''$, 2 ft. $5''$, 7 ft. $4''$, 5 ft. $9''$, 3 ft. $4''$. How many feet are there in all?

4. It is desired to cut a 10-ft. piece of stock into 3 equal lengths, allowing $\frac{1}{8}''$ for saw cut. How long will each piece be?

5. On a straight line extending between two center lines $9''$ apart and at right angles to them, there must be 6 holes equally spaced. How far apart must their centers be?

6. A sheet of steel 3 ft. $6''$ wide is to be sheared into 4 equal strips. How wide will each one be?

7. Four pieces of stock $9\frac{1}{2}''$ long are cut from a piece 4 ft. long. If for each cut there is $\frac{1}{8}''$ waste, how much is left after cutting the 4 pieces?

8. A $\frac{3}{4}''$ counterbore measures $.762''$. How much over-size is it? What is the nearest fractional part of an inch?

9. A drawing calls for stock to be turned to $\frac{17}{32}''$ diameter. If it measures $.526''$, is it over or under size, and how much?

**21. The Micrometer.** The micrometer, Fig. 1, is an instrument used for measuring parts of inches to a greater degree of accuracy than can be measured with the ordinary scale.

It consists of a screw (1) having 40 threads per inch which is turned by a barrel (2) which moves over a scale (3) divided to $\frac{1}{10}$ inch, each of these being in turn divided into four equal parts, making each small division on the scale (3) equal to $\frac{1}{40}$ inch. The inside end of the barrel, which is bevelled, is divided into 25 equal parts. The piece to

be measured is placed between the anvil (4) and the end of the screw (5) and the measurement read from the scale.

There being 40 threads per inch on the screw, the end (5) will move $\frac{1}{40}$ inch or $\frac{25}{1000}$ of an inch for each complete turn of barrel (2) or over one division on the scale. Since the barrel is divided into 25 equal parts, it is an easy matter to find $\frac{1}{25}$ of a revolution, which is $\frac{1}{25}$ of $\frac{1}{40}$ of an inch, or $\frac{1}{1000}$ of an inch.

That is, by means of the bevelled edge divided into

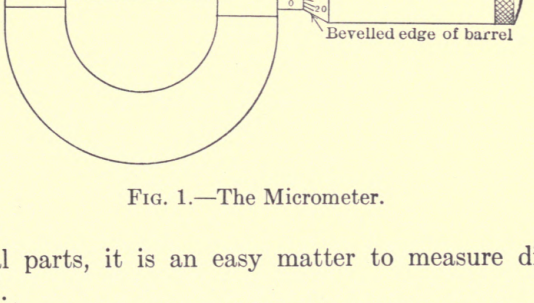



FIG. 1.—The Micrometer.

25 equal parts, it is an easy matter to measure directly to .001″.

**22. Reading a Micrometer.** A reading showing 3 divisions on the screw and division 17 of the bevel lying on the axial line would read as follows:

$$3 \text{ divisions} = \frac{25}{1000} \times 3 \text{ or } \frac{75}{1000}$$

Seventeen divisions on the bevel indicates that the barrel has been moved $\frac{17}{1000}$ beyond the last division on the screw. Therefore, the reading would equal .075″+.017″ or .092″.

### PROBLEMS ON THE MICROMETER

1. A spindle is ground to 1.2765″. What is the setting on the micrometer?

2. An internal gage measures .751″. What is the setting on the micrometer?

3. A micrometer setting shows 7 divisions on the screw and 9 on the barrel. What is the measurement in inches?

4. Three micrometer settings on a plug gage show each 19 divisions on the screw and 24, 23 and $23\frac{1}{2}$ divisions on the barrel. What is the average measurement?

**23. The Vernier Caliper.** A vernier caliper, Fig. 2, is a form of a beam caliper so constructed that by means of

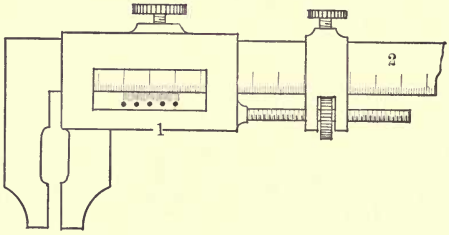



FIG. 2.—The Vernier Caliper.

a sliding scale or vernier (1) measurements can be read directly to the thousandth part of an inch.

The vernier that is used in shop work has the scale on the beam (2) divided into inches, each of which is divided into tenths and each tenth subdivided into four equal parts. This makes each small division equal to $\frac{1}{40}$ or .025 of an inch. The sliding scale (1) is as long as 24 of these small divisions and equal $24 \times .025$ or .600″, but is divided up into 25 equal parts. This would make each

small division on the slide $\frac{1}{25}$ of .600″ or .024″ which is .001″ less than the division on the beam.

By referring to Fig. 3, which represents an enlarged portion of the slide and beam, it is seen that the 25 divisions on the slide exactly coincide with the 24 on the beam; also from the foregoing the difference between the first division on the slide and the first division on the beam is .001″, and the difference between the second division on the slide and the second division on the beam is .002″, and between the third it is .003″, and so on.

By moving the slide until its first division lines up exactly with the first division on the beam, the opening between the

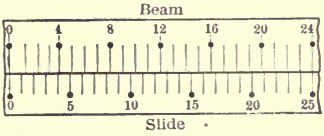



Fig. 3.—Vernier Slide Enlarged.

jaws has measured .001″; if moved until the second division on the slide coincides with the second on the beam the opening measures .002″. If moved still further until the 23d division on the slide corresponds with a division on the beam, the slide has moved through .023″.

To read a vernier, note the opening of the jaws up to the "0" mark on the slide. To this reading add the number of the slide division which coincides with a division line on the beam.

Example. In using a vernier caliper on a jig, the jaws are opened until the reading to the "0" mark on the slide measures 1″, 3 tenths and 3 of the smallest divisions. This equals 1.375″. Upon examination it is seen that the

"0" division does not coincide with a line on the beam but extends beyond until the eleventh division of the slide coincides with a beam division. This means that the "0" division on the slide which marks the correct reading extends .011″ beyond that reading already given, making the corrected measurement read 1.386″.

### PROBLEMS ON THE VERNIER CALIPER

1. A reading on the vernier shows 2″, 6 tenths, 1 small division, while the 19th division on the slide lines up with a beam division. What is the correct reading?

2. What would be the correct setting for a vernier caliper to read 1.729″?

3. In checking up a jig the readings on the vernier show 1″, and the 7th division on the scale coincides with a beam division. Other readings on other parts of same jig show 2″, 4 small divisions, while the "0" mark of the slide coincides with the beam; also a reading of 1″, 7 tenths and the 15th division on the slide coinciding with the division on the beam. What are these readings, expressed in inches?

4. To read 2.007″, what would be the correct setting of a vernier caliper?

## 24. Square Measure.

144 sq.ins. = 1 sq.ft.;
9 sq.ft. = 1 sq.yd.;
4840 sq.yds. = 1 acre;
640 acres = 1 sq. mile.

An acre is equivalent to a square which measures $69\frac{1}{2}$ yds. on the side.

## 25. Comparison with Metric System.

1 sq. meter = 10.76 sq.ft. or 1.19 sq.yds.;
1 sq.ft. = 0.093 sq. meter;
1 sq.yd. = 0.836 sq. meter.

## 26. Methods of Calculating Areas Common to Shop Use.

**Square.** Area of square $= a \times b$.

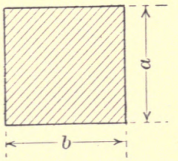



Fig. 4.

Application of Formula. What is the area of a square bar measuring 4″ on a side?

*Solution.* $4 \times 4 = 16$ sq.ins.

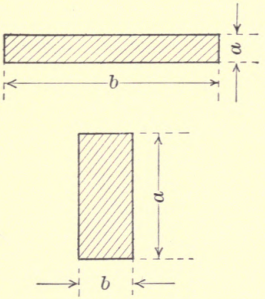



Fig. 5.

**Rectangle.** Area of rectangle $= a \times b$.

Application of Formula. A strip of steel measures $1\frac{1}{2}'' \times 3''$ in cross-section. What is the area?

*Solution.* $\frac{3}{2} \times 3 = \frac{9}{2} = 4\frac{1}{2}$ sq.ins.

**Circle.** Circumference of circle $=$ $3.1416 \times$ diameter $(d)$.

Area of circle $= d \times d \times .7854$.

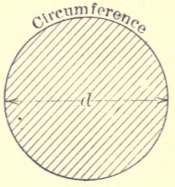



Fig. 6.

Application of Formula. What is the area in square inches of a shaft $3\frac{1}{2}''$ in diameter?

*Solution.* $\frac{7}{2} \times \frac{7}{2} \times .7854 = 9.6211$ sq.ins.

**Ellipse.** Area of ellipse $= a \times b \times .7854$.

Circumference of ellipse = square root of $\left(\frac{a^2+b^2}{2}\right) \times 3.1416$.

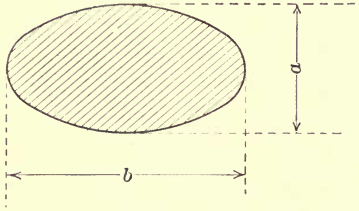



Fig. 7.

Application of Formula. A pulley arm elliptical in section measures $\frac{3}{4}''$ across short axis and $2''$ across long axis. What is the area of the section?

*Solution.* $\frac{3}{4}'' \times 2'' \times .7854 = 1.1781$ sq.ins.

**Triangle.** A triangle is a plane figure with three sides.

Area of triangle $= \frac{1}{2}$ base $\times$ altitude.

Application of Formula. A "V" slot in a planer block measures $\frac{3}{4}''$ deep and $1\frac{1}{2}''$ across the V. What is the area of the V cut?

*Solution.* $\frac{3}{4} \times \frac{3}{2} \times \frac{1}{2} = \frac{9}{16}$ sq.ins.

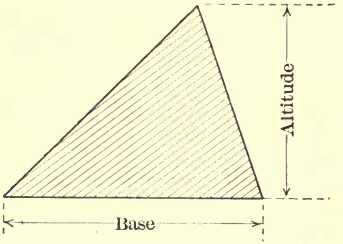



Fig. 8.

**Parallelogram.** A parallelogram has opposite sides equal and parallel.

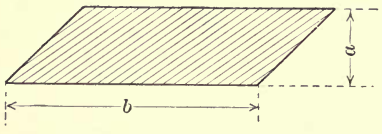



Fig. 9.

Area of parallelogram $= a \times b$.

Application of Formula. A steel bar, diamond shape in section with parallel sides, measures 1.732" thick

and is 2″ on the side. What is the area through the bar?

*Solution.* $1.732 \times 2 = 3.464$ sq.ins.

**Trapezoid.** A trapezoid is a plane figure which has only two opposite sides parallel but unequal in length.

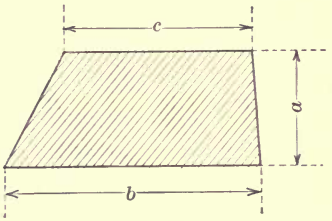


Fig. 10.

Area of trapezoid $= \frac{1}{2}(b+c) \times a$.

Application of Formula. A slot is cut in a casting to receive a slide block. The cut is $\frac{3}{4}$″ deep and measures 3″ across the top and 2″ across the bottom. What is the area through the cut?

*Solution.* $(3+2) \div 2 \times \frac{3}{4} = 1\frac{7}{8}$ sq.ins.

**27. Shapes Used in Construction.** In an angle shape the legs may be equal or unequal, also thicknesses of the legs may be equal or unequal.

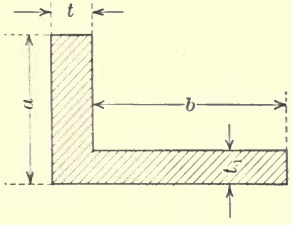


Fig. 11.

**Angle Section.** Area of angle section $= (a \times t) + (b \times t_1)$.

Application of Formula. An angle section milled from a piece of steel measures $\frac{1}{2}$″ thick; on the back of the angle the measurements are 2″ and 3″. What is the area of the section?

*Solution.* $(2 \times \frac{1}{2}) + (2\frac{1}{2} \times \frac{1}{2}) = 2\frac{1}{4}$ sq.ins. area.

In this section the flanges may be equal or unequal, also the thicknesses may be equal or unequal.

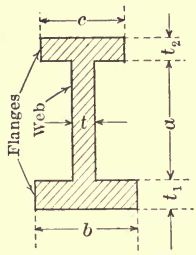



Fig. 12.

**I-Section.** Area of I-section $= (a \times t) + (b \times t_1) + (c \times t_2)$.

Application of Formula. A special I-section has flanges $\frac{3}{4}''$ thick and 4″ long. The web measure $\frac{3}{4}'' \times 6''$. What is the area of the section?

*Solution.* $(\frac{3}{4}'' \times 4'') + (\frac{3}{4}'' \times 4'') + (\frac{3}{4}'' \times 6'') = 10\frac{1}{2}$ sq.ins. area.

**Channel.** In a channel section the web or flanges may be equal or unequal, also thicknesses may be equal or unequal.

Area of channel section $= (a \times t) + (b \times t_1) + (c \times t_2)$.

Application of Formula. In a channel iron the web and flanges are $\frac{3}{4}''$ thick. Each flange extends 4″ out from the web, the web measuring 9″ on the outside. What is the area of a cross-section of the iron?

*Solution.* $(9 \times \frac{3}{4}') + (4 \times \frac{3}{4}'')' + (4 \times \frac{3}{4}'') = 12\frac{3}{4}$ sq.ins. area.

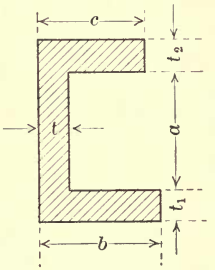



Fig. 13.

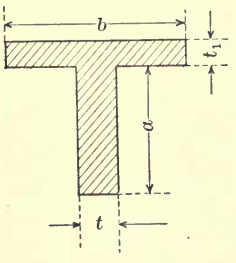



Fig. 14.

The upright and flanges of this section may be equal or unequal and the thicknesses may be equal or unequal.

**T-Section.** Area of T-section $= (a \times t) + (b \times t_1)$.

Application of Formula. A T-shaped section has one flange 8″ long and $\frac{5}{8}''$ thick, the other flange measuring $\frac{3}{4}'' \times 4''$. What is the area of the T?

*Solution.* $(8 \times \frac{5}{8}) + (\frac{3}{4} \times 4) = 8$ sq.ins. area of section.

**Cross.** The arms in a cross-shaped section may be equal or unequal; the thicknesses are generally equal.

Area of cross-section $= (a \times t) + (b \times t) + (c \times t)$.

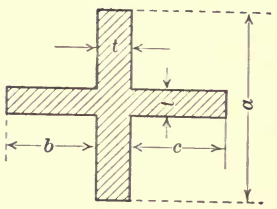


FIG. 15.

APPLICATION OF FORMULA. A column having a cross-shape section has two opposite arms of the cross $4\frac{1}{2}''$ long, the other two arms $4''$. The arms are $\frac{1}{2}''$ thick. What is the area of section?

*Solution.* $(\frac{1}{2} \times 4\frac{1}{2}) + (\frac{1}{2} \times 4\frac{1}{2}) + (\frac{1}{2} \times 8\frac{1}{2}) = 8\frac{3}{4}$ sq.ins. area.

**28. Rules in Computing Areas.** To change area in square feet to square inches, multiply the area in square feet by 144.

To reduce area in square inches to area in square feet, divide area in square inches by 144.

To find the area of an irregular figure whose area cannot be calculated by the above rules, divide it up into sections whose areas can be calculated and add these areas together.

**29. Board Measure.** Lumber is bought and sold by the *board foot* at a certain cost per thousand, meaning thousand board feet and usually designated by the capital letter "M". It is sold "rough" or "dressed," according to whether the surfaces are planed or left rough as it comes from the saw. As a rule it is well to allow $\frac{1}{8}''$ for "dressing" (planing) the lumber to size. Also, in ordering lumber it is advisable to know what standard lengths are carried by dealers in your locality, for if cut to special lengths more time will be required for delivery, the material costs more, and there usually will be considerable waste. Common standard lengths are 10 ft., 12 ft., 14 ft., etc.,

increasing in length by two feet, while the thicknesses are sawed to $\frac{3}{4}''$, $1''$, $1\frac{1}{4}''$, $1\frac{1}{2}''$, $2''$, $2\frac{1}{2}''$, $3''$, and so on.

*To find the number of board feet in a piece of lumber, multiply the length in feet by the width in feet when the lumber is 1″ or less in thickness. If it is over 1″ thick, the board feet are found by multiplying the length in feet by the width in feet by the thickness in inches.*

EXAMPLE. What is the cost of 40 pine boards 10 ft. long by 6″ wide, by $\frac{3}{4}''$ thick, and 22 pine boards 8 ft. long, 8″ wide and $1\frac{1}{2}''$ thick, at $60.00 per thousand?

*Solution.*

$\frac{10\times6}{12}=5$ board-feet in each of the 10-ft. boards;

$40\times5=200$ board-feet in 40 boards;

$\frac{8\times8\times3}{12\times2}=8$ board-feet in each 8-ft. board;

$22\times8=176$ board-feet in 22 boards;

$200+176=376$ total board-feet;

$376\times\$0.06=\$22.56=$ cost of lumber.

## PROBLEMS INVOLVING BOARD MEASURE

1. A storage bin calls for 10 strips of $2''\times4''$, 6 ft. long; 21 boards $1\frac{1}{4}''\times6''\times12$ ft. At the rate of $25.00 per thousand, what will this material cost, and what would be the most advisable length in which to order it?

2. An order of 30 saw horses to be used for drafting-room purposes calls for 16 ft. of pine $\frac{7}{8}''\times4''$, and 4 ft. of pine $1\frac{1}{2}''\times3''$ per saw horse. How much material is required for the job? What is its cost at $62.00 per thousand?

3. To build an office filing case requires 6 oak boards $\frac{3}{8}''\times8''\times4$ ft., 4 oak boards $\frac{3}{8}''\times6''\times3$ ft., and 16 ft. of $\frac{1}{4}''$ whitewood

8″ wide. These given dimensions are finished sizes. If oak sells for $85.00 per thousand and whitewood $56.00 per thousand, what is the cost of this material?

4. At $7.50 per hundred what is the cost of the lumber used in building 4 hurdles as per drawing, Fig. 16?

5. How many board feet of 1″ hemlock 12″ wide are needed in building a 6-ft. sidewalk 48 ft. long?

These boards are to be nailed crossways to 4 stringers of

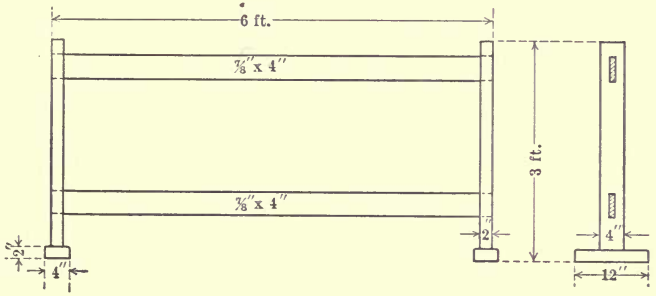



Fig. 16.

2×4 running the full length of the walk and no allowance is to be made for cracks between the boards. In what lengths should this material be ordered? At $53.00 per thousand what is the total cost of material used in building the sidewalk?

## REVIEW PROBLEMS

1. A hollow square brass tube measures $1\frac{1}{4}$″ outside and $\frac{5}{8}$″ inside. Find area of cross-section.

2. What is the cross-section area of a hollow tile, the outside measuring 17″×$8\frac{1}{2}$″, the opening $14\frac{1}{2}$″×6″?

3. A grinder pedestal through smallest section measures 10″×6″, the core at the same place is $8\frac{1}{4}$″×4″. What is the area through this section?

4. Find the area through a horizontal section of a lathe bed that measures 54″×10″, the metal is $\frac{3}{8}$″ thick?

5. A brass disk $7\frac{1}{2}''$ in diameter has four $\frac{7}{8}''$ holes and one $1\frac{1}{4}''$ hole drilled in it. Find the area of the disc after the drilling operation.

6. A tank to be lined with a sheet of copper $\frac{1}{16}''$ thick shows inside measurements of tank to be 13″ in diameter by 22″ high. Give the size of piece necessary.

7. A 16″ disk of $\frac{1}{2}''$ W. I. has drilled in it six 2″ holes to lighten the weight. How much is the reduction in surface? How much in weight?

8. 36 strips of $\frac{1}{8}''$ brass $1\frac{1}{4}''\times 7''$ are needed on a certain job. How many square feet will be necessary?

9. An order of lumber shows 10 basswood boards 12 ft.$\times 8''\times \frac{3}{8}''$, 9 basswood boards 10 ft.$\times 6''\times \frac{1}{2}''$, 14 oak boards 10 ft.$\times 8''\times \frac{5}{8}''$, and 12 pieces $2''\times 4''$ pine 9 ft. long. How many board feet are there in all?

10. Pine used in pattern-making cost $65.00 per 1000 ft. In building a certain pattern and core box, 45 ft. are used. How much does this material cost?

11. Lumber selling for $60.00 per thousand is used in building shelves in a store room. Six boards 8 ft.$\times 9''\times 1''$, 4 boards 6 ft.$\times 8''\times 1''$, and 20 boards 6 ft.$\times 6''\times \frac{7}{8}''$ are used in the construction. What is the cost of the lumber?

### 30. Cubic Measure.

1728 cu.in. = 1 cu.ft.
27 cu.ft. = 1 cu.yd.

### 31. Comparison with Metric System.

1 cu.ft. = 0.0283 cu. meter;
1 cu. meter = 35.31 cu.ft.;
1 liter = 0.264 gallon = 1.057 quarts = 61.02 cu.ins;
1 gallon = 3.785 liters.

**32. General Rules.** The volume of tanks holding fluids such as water, oil, etc., is generally given in gallons or cubic feet.

The capacity in gallons is found by dividing the volume in cubic inches by 231, as there are 231 cubic inches in a gallon, or by multiplying the number of cubic feet by 7.48, as each cubic foot contains 7.48 gallons.

The volume in cubic feet is obtained from the volume in cubic inches by dividing the volume in cubic inches by 1728, or in case the volume is given in gallons, by dividing the number of gallons by 7.48.

To find the weight of water in a tank multiply the number of cubic feet by 62.5, there being 62.5 lbs. in 1 cu.ft. of water. If the volume of the tank is given in gallons, multiply the number of gallons by $8\frac{1}{3}$, as each gallon of water weighs approximately $8\frac{1}{3}$ lbs.

**33. Rules for Finding the Volumes of Regular Figures.** Volume of rectangular shape = area bottom × height.

Volume of cylindrical shape = area base × height.

Length of cylinder = volume ÷ area of base.

Volume of sphere shape = $4.1888 \times (\text{radius})^3$, or $0.5236 \times (\text{dia.})^3$.

Volume of cone or pyramid = area of base × $\frac{1}{3}$ vertical height.

Volume of frustrum of cone or pyramid = $\frac{1}{3}$ the vertical height multiplied by the combined sum of the area of top, area of bottom, and the square root of the product of the top and bottom areas. Volume of irregular solids is found by dividing them up into parts resembling the rectangular or other shapes whose volumes can be found by the above methods.

### PROBLEMS ON THE CALCULATION OF VOLUMES

1. How many gallons of water in a reservoir $8\frac{1}{2}$ ft. in diameter and 5 ft. high? What is its weight?

2. A cylindrical tank must be built so as to hold 15 gallons of gasolene; the tank is to fit in a space that cannot accommodate

over a $3' \times 3' \times 2'$ size. What would be suitable dimensions for such a tank? If made of copper $\frac{1}{16}''$ thick, what would be the weight of tank when filled with 15 gallons of gasolene, assuming a gallon of gasolene to weigh 7.5 lbs.?

3. A tank 4 ft. in diameter and 5 ft. high is $\frac{3}{4}$ filled with machine oil. What is the pressure on the bottom of the tank? (This oil weighs 7.9 lbs. per gallon.)

4. An automobile gasolene tank has an elliptical cross-section $9'' \times 15''$ and is 3 ft. long. How many gallons of gasolene will it hold?

5. A water tank 12 ft. high measures 12 ft. in diameter at the bottom and 9 ft. at the top. When it is $\frac{3}{4}$ full, how many gallons of water are in it? What is the weight of the water?

**34. Weights of Materials.** The weight of a solid is found by multiplying the volume in cubic inches by the weight of a cubic inch of the solid.

Knowing the weight of pine patterns free from cores, the weights of the iron castings taken from them may be found by multiplying the weight of the pattern by 16. If the patterns are mahogany and free from cores, multiply by 9. The weights of bronze castings or steel castings may be found by multiplying weight of pine patterns from which castings are made, by 19 for bronze and by 16.5 for steel. If mahogany patterns are used, 11 and 9.6 are used for bronze and steel respectively.

| | | | |
|---|---|---|---|
| 16 ounces (oz.) | = 1 pound (lb. or pd.) | | |
| 100 lbs. | = 1 hundred weight (cwt.) | | |
| 2000 lbs. (20 cwt.) | = 1 ton | | |
| Cast iron (C. I.) | = .26 lb. | per | cubic inch |
| Steel (S.) | = .28 | " | " |
| Wrought iron (W. I.) | = .27 | " | " |
| Brass (B.) | = .30 | " | " |
| Copper (C.) | = .31 | " | " |
| Bronze (Brz.) | = .30 | " | " |
| Lead | = .41 | " | " |

| | | |
|---|---|---|
| Zinc | =.25 lb. | per cubic inch |
| Tin | =.26 " | " |
| Aluminum | =.09 " | " |
| Babbitt | =.26 " | " |
| Water (pure) | =62.5 | lbs. per cubic foot |
| Sea water | =64.3 | " " |
| White pine (average) | =25 to 30 | " " |
| Yellow pine " | =40 | " " |
| Cedar " | =35 | " " |
| Chestnut " | =38 | " " |
| White oak " | =50 | " " |
| Concrete " | =145 | " " |
| Earth (loose) " | =76 | " " |
| Earth (rammed) " | =100 | " " |
| Stone | =135 to 200 | " " |
| Brick | =125 to 200 | " " |

## PROBLEMS INVOLVING CALCULATION OF WEIGHTS

1. What is the weight of 42 cast-iron brackets like the sketch, Fig. 17?

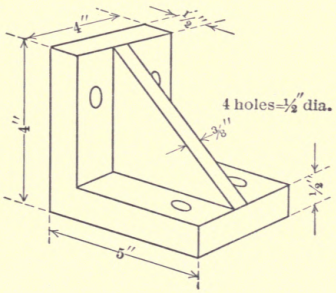



FIG. 17.

2. Find the weight of arbor press handle like the sketch, Fig. 18.

3. Find the weight of a hollow steel spindle 14" long, $1\frac{3}{4}$" in diameter, the hole being $\frac{7}{8}$" in diameter.

4. A cast-iron column measuring $8\frac{1}{2}$" outside diameter, has a

cored hole 6″ diameter throughout its length. Find its weight if the column is 14 ft. high.

5. Find the weight of a cast-iron sleeve for square rod if outside measures $2\frac{3}{8}$″ square, inside measures $1\frac{5}{8}$″ square and the sleeve is $3\frac{1}{2}$″ long.

6. A bronze plate $3\frac{1}{4}$″ in diameter and $\frac{1}{2}$″ thick has a slot

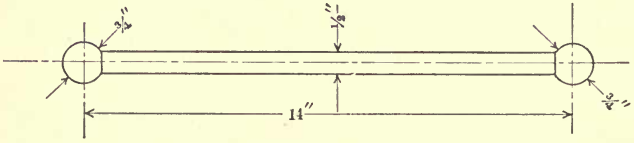



Fig. 18.

$\frac{3}{4}$″×2″ cut through the center. Find the weight of plate, if bronze weighs .31 lb. per cubic inch.

7. A cast-iron billet in the shape of a frustrum of a square pyramid is used on a pile-driving machine. The billet is 14″ high and measures 10″ square on the bottom and 6″ square on the top. What is its weight?

8. In excavating for a foundation for columns, 32 holes 6′×6′×4′ were dug. How many cubic yards were removed and what was its approximate weight, assuming that the earth was well packed before digging?

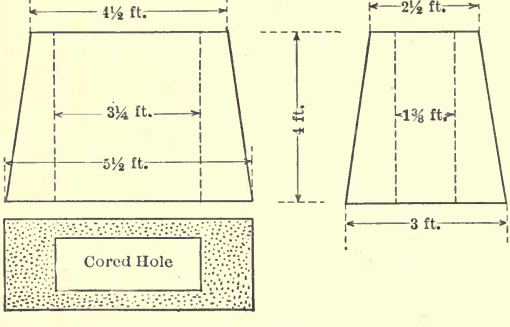



Fig. 19.

9. These 32 foundations are to be made of concrete as per the specifications, Fig. 19. What is the approximate weight of the concrete filling?

10. A concrete watering trough measures 2 ft. deep, $3\frac{1}{2}$ ft. wide by

8 ft. long outside; while inside, the basin measures 1 ft. 6″ deep, 2 ft. 10″ wide, 7 ft. 4″ long. What is its approximate weight? If the concrete was mixed in the proportions 1, 2, 3 so that $\frac{1}{6}$ of the weight of the trough was cement, how many bags of cement were used if each bag weighed 90 lbs.?

11. A pile of 36 yellow pine timbers measuring 8″×8″×10 ft. long is stored in an attic. What is the approximate weight that this pile exerts upon the attic floor?

12. What is the weight of 2 cast-iron brackets as per the specifications of Fig. 20?

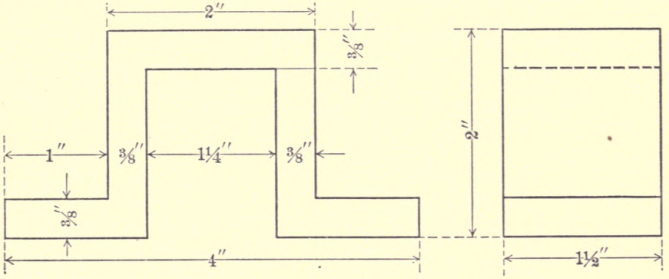



FIG. 20.

**35. Weights of Plates and Bars.** For convenience in finding the weights of plates and bars of cast iron, wrought iron and steel, the following is tabulated:

| Thickness in Inches. | Weight per Square Foot. | | Thickness in Inches. | Weight per Square Foot. | |
|---|---|---|---|---|---|
| | Cast Iron. | Wrought Iron and Steel. | | Cast Iron. | Wrought Iron and Steel. |
| $\frac{3}{16}$ | 7.03 | 7.58 | $\frac{7}{8}$ | 32.8 | 35.4 |
| $\frac{1}{4}$ | 9.37 | 10.1 | 1 | 37.5 | 40.4 |
| $\frac{3}{8}$ | 14.1 | 15.2 | $1\frac{1}{4}$ | 46.9 | 50.5 |
| $\frac{1}{2}$ | 18.8 | 20.2 | $1\frac{1}{2}$ | 56.3 | 60.6 |
| $\frac{5}{8}$ | 23.4 | 25.3 | 2 | 75.0 | 80.8 |
| $\frac{3}{4}$ | 28.1 | 30.3 | | | |

EXAMPLE ILLUSTRATING USE OF ABOVE TABLE. A cast-iron plate measuring 1″ thick, 2 ft. square, costs 3 cents per lb. What is the total cost of the plate?

From the tabulation above, cast iron plate 1″ thick weighs 37.5 lbs. per square ft.

A piece 2 ft. square measures 2 ft. on side of square and contains 4 sq.ft. 4 sq.ft. cast iron weighs 37.5×4 or 150 lbs. At 3 cents per pound this would cost $4.50.

**36. Weights of Steel in Pounds per Linear Foot.**

| Size in Inches. | Round. | Square. | Size in Inches. | Round. | Square. |
|---|---|---|---|---|---|
| $\frac{1}{2}$ | .67 | .85 | $2\frac{1}{2}$ | 16.7 | 21.1 |
| $\frac{3}{4}$ | 1.51 | 1.90 | $2\frac{3}{4}$ | 20.2 | 25.7 |
| $\frac{7}{8}$ | 2.05 | 2.61 | 3 | 24.1 | 30.6 |
| 1 | 2.68 | 3.40 | $3\frac{1}{2}$ | 32.7 | 41.8 |
| $1\frac{1}{4}$ | 4.17 | 5.32 | 4 | 42.8 | 54.4 |
| $1\frac{1}{2}$ | 6.01 | 7.66 | $4\frac{1}{2}$ | 54.1 | 68.9 |
| $1\frac{3}{4}$ | 8.19 | 10.42 | 5 | 66.9 | 85.1 |
| 2 | 10.74 | 13.61 | $5\frac{1}{2}$ | 80.9 | 102.9 |
| $2\frac{1}{4}$ | 13.52 | 17.21 | 6 | 96.2 | 122.5 |

EXAMPLE ILLUSTRATING USE OF ABOVE TABLE. A steel bar $1\frac{3}{4}$″ square and 2 ft. long is required on a certain job. If the stock sells at 8 cents per pound, what is the cost of the bar?

*Solution.* Steel $1\frac{3}{4}$″ square weighs 10.4 lbs. per running foot, as given in the above table. Then a piece 2 ft. long would weigh 20.8 lbs.

At 8 cents per pound this would cost $1.66.

## PROBLEMS

1. In taking inventory a stock clerk finds he has not accounted for 6 bars of $1\frac{1}{4}''$ round steel, 2 of which are 9 ft. long, and 4 of which are $6\frac{1}{2}$ ft. long. At $11\frac{1}{2}$ cents per pound what would this amount to?

2. To make out a certain cost-card requires that there be recorded at 13 cents per pound, 2 pieces of $\frac{7}{8}''$ square stock each 3 ft. long, and 3 pieces of $\frac{5}{8}''$ round stock one of which is $1\frac{3}{4}$ ft. long, another 5 ft. long, and another $4\frac{1}{4}$ ft. long. What is the equivalent cost of these?

3. Two cast-iron plates $\frac{7}{8}''$ thick and 18″ square are needed in making a rubber mould. At $3\frac{1}{2}$ cents per pound what will these castings cost?

4. What is the weight of rolled steel plate $\frac{1}{4}''$ thick used in making a chemical tank which measures $2\frac{1}{2}$ ft. in diameter and is $4\frac{1}{2}$ ft high? An allowance of 1″ is made for the lap on the cylindrical part, and the diameter of the bottom is also extended 2″ for riveting it to the upright.

## CHAPTER III

### PULLEYS AND BELTING

**37. Belts.** Power is carried from one line of shafting to another by means of belts which pass over pulleys fastened to the shafts.

If these belts are *open* the pulleys turn in the same direction, if *crossed* they turn in the opposite direction.

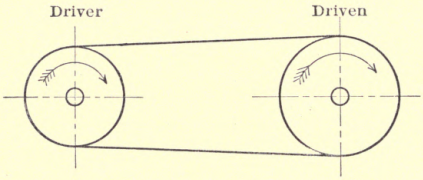



FIG. 21(*a*).—Open Belt.

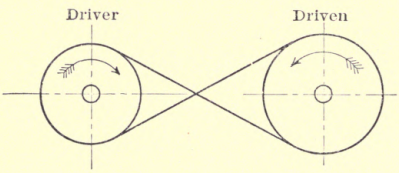



FIG. 21(*b*).—Crossed Belt.

The pulley supplying the motion is the driving pulley, or the *driver*, while the one receiving the motion is the *driven pulley*.

**38. Pulley Speeds.** Provided there is no belt slip, the

rim speed of the driving pulley will equal the rim speed of the driven pulley, and in each case will be the same as the speed of the belt which clings to the pulley. The rim speed of a pulley, or the speed of the belt which drives the pulley, is found by multiplying the revolutions per minute (R.P.M.) of the pulley by its circumference measured in feet.

EXAMPLE. A line shaft running at 152 R.P.M. has an 18″ pulley driving a countershaft. What is the speed of the belt passing over this pulley?

*Solution.* $\frac{18\times3.1416}{12}\times152=716.3$ ft. per minute = rim speed.

In case the rim speed and the diameter of the pulley are given and it is desired to find the R.P.M. of the pulley, the rim speed in feet per minute is divided by the circumference of the pulley in feet.

To prove that the result obtained is correct, use the diameter and the new R.P.M. in working out a new problem to see if the resultant rim speed is the same as the original.

EXAMPLE. The rim speed of an 18″ pulley is 1250 ft. per minute. How many R.P.M. does the pulley make?

*Solution.* $1250\div\left(\frac{18\times3.1416}{12}\right)=265.25$ R.P.M.

*Check on the above.* With this R.P.M. and the given diameter, the rim speed would be $265.25\times18\times3.1416=$ 1249.96 ft. per minute. This is practically equivalent to 1250, hence the R.P.M. is correct.

**39. Belt Slip.** If the belt does not cling tight enough to the pulley it will slip, and so will not have the same speed as the rim of the pulley which it drives. This amount of slip may be found by indicating the R.P.M. of the pulley with a speedometer and subtracting this amount from

the calculated R.P.M. The amount of slip is usually expressed as a per cent.

The rim speeds of two or more pulleys fastened to the same shaft bear the same proportion as to their diameters.

### PROBLEMS INVOLVING SPEEDS OF PULLEYS AND BELTS

1. A 14″ pulley makes 310 R.P.M. What is the rim speed of the pulley?
2. A pulley 5¼″ in diameter on a small press motor runs at 1350 R.P.M. What is its rim speed?
3. If the belt speed on a line shaft is 2500 ft. per minute, and the belt passes over a 14″ pulley and drives a 10″ pulley, what is the R.P.M. of each pulley?
4. The speed indicator shows that the surface speed of a 12″ pulley is 1400 ft. per min. What is the R.P.M. of a 16″ pulley which acts as the driver of this 12″ pulley?
5. A 12″ circular saw runs at 2450 R.P.M. What is its cutting speed? (Cutting speed is the amount of cutting surface passing a given point per minute, hence is the same as rim speed in feet per minute.)
6. What is the rim speed of a 12 ft. flywheel running at 135 R.P.M.?
7. A flywheel having a rim speed of a mile a minute makes 120 R.P.M. What is its diameter?
8. A 10″ emery wheel has a cutting speed of 4820 ft. per minute. How many R.P.M. does it make?
9. A bandsaw runs over 2 pulleys 36″ diameter. The pulley runs at 352 R.P.M. What is the cutting speed of the saw?
10. An emery wheel 14″ diameter makes 1200 R.P.M. What is the cutting speed?

**40. Rule for Pulley Speeds and Diameters.** *When three items are known about two pulleys that are connected by belts, and it is necessary to find the fourth item, multiply together those two items that are known about one pulley and divide this product by the other item belonging to the second*

*pulley. The result will be either the R.P.M. or the diameter, whichever is needed.*

EXAMPLES. 1. A 16″ pulley running at 150 R.P.M. drives a 24″ pulley. How many R.P.M. does this pulley make?

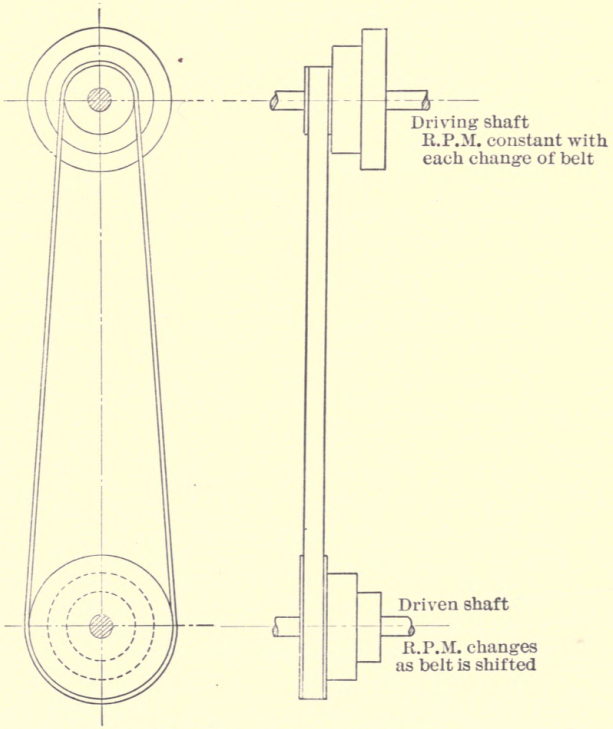



FIG. 22.—Step-cone Pulleys.

*Solution.* $\frac{16\times150}{24}=100=$ R.P.M. of pulley.

2. A pulley of a shaft running at 120 R.P.M. drives a 24″

pulley at 180 R.P.M. What is the diameter of the driving pulley?

*Solution.* $\frac{180\times 24}{120}=36''$ diameter of driving pulley.

To secure different R.P.M. from the driving shaft, a cone pulley may be used on both the driving shaft and the driven shaft. Because of the difference in the sizes of the circumferences of the steps on the cone this change in R.P.M. can be accomplished.

Example on Step-cone Pulley. A cone pulley having steps equal to 11", 8", 5", running at 120 R.P.M., drives a step-cone pulley having diameters of 4", $6\frac{1}{2}$", 9". What are the ranges of speeds that can be obtained?

*Solution.*

$\frac{120\times 11}{4}=330$ R.P.M. driving from large step of driver;

$\frac{120\times 8}{6.5}=148$ R.P.M. driving from middle step of driver;

$\frac{120\times 5}{9}=67$ R.P.M. driving from small step of driver.

**41. Rule for Finding Length of Belt over Pulleys.** *When the belt is of open style, the length of belt* $=3.1416\times$ *(radius small pulley in inches* $+$ *radius of large pulley in inches)* $+2\times$ *distance between centers in inches* $+\frac{(R-r)^2}{12\times D}$.

$D=$ *distance between centers of pulleys expressed in feet.*

*When the belt is of crossed style the length is*

$$3.1416(R+r)+2D+\frac{(R+r)^2}{D},$$

*where R, r, and D are expressed inches.*

EXAMPLES. 1. A 14″ pulley and a 20″ pulley 12 ft. apart are connected by an open belt. How long is the belt?

$$3.1416(10+7)+(2\times144)+\frac{(10-7)^2}{144}=28.46 \text{ ft. length of belt.}$$

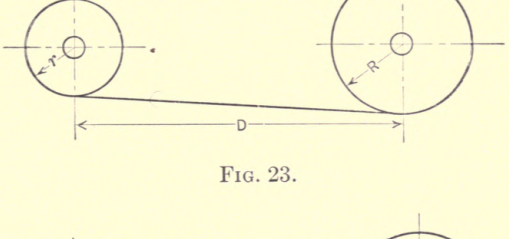



FIG. 23.

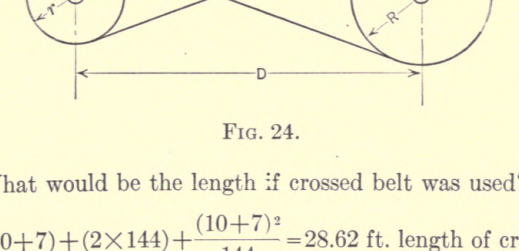



FIG. 24.

2. What would be the length if crossed belt was used?

$$3.1416(10+7)+(2\times144)+\frac{(10+7)^2}{144}=28.62 \text{ ft. length of cross belt.}$$

## GENERAL PROBLEMS INVOLVING PULLEY CALCULATIONS

1. A 14″ pulley running at 200 R.P.M. drives an 8″ pulley. Find the R.P.M. of the 8″ pulley.

2. It is found necessary to run a countershaft at 310 R.P.M. If driven from an 18″ pulley at 175 R.P.M., what must be the diameter of the pulley on the countershaft? How long must a crossed-style belt be if the centers are $10\frac{1}{2}$ ft. apart?

3. A separate line of shafting running at 200 R.P.M. is to be

driven from another line running at 150 R.P.M. and located 12 ft. from it. Give two suitable sizes of pulley and find the length of belt used if the belting is of the open type.

4. A countershaft running at 250 R.P.M. has a cone pulley with steps 11″, 9″ and 7″ driving a cone on a lathe with steps 7″, 5″ and 3″. What different speeds can be obtained by this arrangement?

5. It is desired to change the cutting speed of a 14″ emery wheel to 4000 ft. per minute. The wheel is to be driven from a 14″ pulley on a countershaft making 300 R.P.M. What size pulley must be used on the emery wheel and what length open belt is needed, the distance between centers being $7\frac{1}{2}$ ft.?

6. A countershaft with a 14″ pulley must be driven at a speed of 390 R.P.M. What size pulley must be put on the line shaft which runs at 210 R.P.M.? How long an open belt must be used if centers of shafts are 9 ft. apart?

7. An engine which runs at 85 turns a minute drives a 5 ft. pulley on a line shaft from a 12 ft. flywheel. This line shaft in turn drives from a 28″ pulley a jackshaft with an 18″ pulley. Find the R.P.M. of the jackshaft.

8. A jackshaft with a 12″ pulley running at 410 R.P.M. drives a 14″ emery wheel with a 4″ pulley. What is the cutting speed of the wheel? What will it be when wheel is worn down to 10″ diameter?

9. In a set of cone pulleys, the driving cone has steps 10″, 7″ and 4″ in diameter. The other cone has steps 9″, 6″ and 3″. If the driving shaft makes 210 R.P.M., what are the R.P.M. of the driven cone as the belt is shipped from step to step?

10. In arranging two pulleys to give 174 R.P.M. to the driven shaft, a 12″ pulley was put on the driving shaft, which ran at 120 R.P.M. Find the size of pulley on the driven shaft.

11. Show an arrangement of pulleys that will give 210 R.P.M. to the driven shaft when the driving shaft makes 135 R.P.M. The pulleys must be over 10″ diameter. What is the length of belt if the crossed style is used and the centers of pulleys are 10 ft. apart?

12. A 16″ emery wheel has a cutting speed of 5000 ft. per minute. The wheel is driven by a 3″ pulley on the same spindle which takes the belt from a 10″ pulley. Find the R.P.M. of the 10″ pulley.

13. An 8″ pulley on a countershaft runs at 420 R.P.M. If driven from a line shaft that makes 180 R.P.M. what size pulley is used on the line shaft?

14. A 24″ pulley running at 200 R.P.M. drives a 16″ pulley. Find the R.P.M. of the 16″ pulley. If the driving is by means of a crossed belt, what is the length of belt used? The centers of the pulleys are 14 ft. apart.

15. A fan pulley 4″ in diameter is driven at 800 R.P.M. by a pulley on a line shaft running at 175 R.P.M. What is the diameter of the pulley?

16. A line shaft running at 225 R.P.M. drives from a 22″ pulley a 6″ pulley on a grinder. How many R.P.M. does the grinder make?

17. What is the length of belt if the centers of the pulleys in the above case are $9\frac{1}{2}$ ft. apart?

**42. Methods of Connecting Pulleys by Belts.** In arranging pulleys on shafting it must be remembered that unless the driving side of the belt is delivered to the center of the face of the driven pulley, it will run off. However, it is not necessary that the belt leave in the center of the face of the driving pulley.

To accomplish the above, it is sometimes necessary to use guide pulleys. This may be more clearly seen by a study of the drawings of pulley connections shown in Figs. 27 and 28.

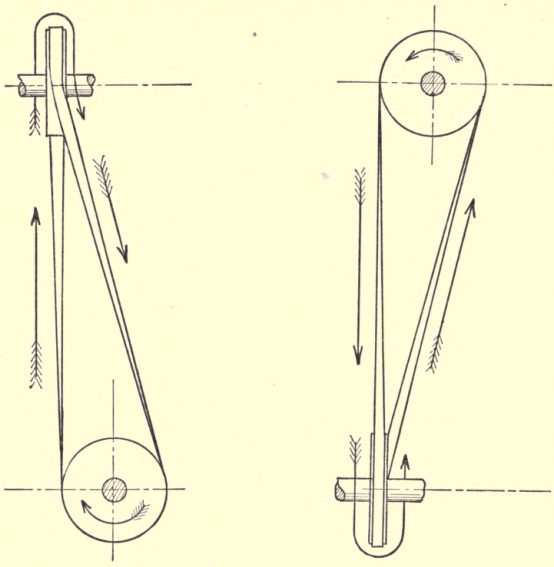


FIG. 25.—Quarter-turn Belt.

This style of belting is used to connect shafts that are at any angle between 0° and 90° with each other.

In this case the belt can travel in only one direction. The pulleys used should be small enough and far enough apart to prevent strain or slip in the belt as it leaves the pulley.

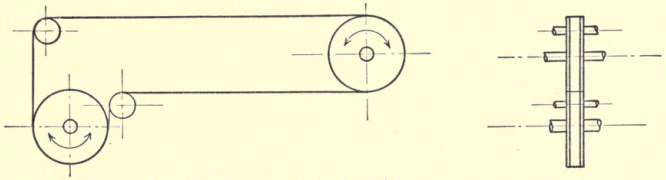


FIG. 26.—Special Belt Connection.

Used where direct connection is impossible because of conditions interfering. Belt may run in either direction.

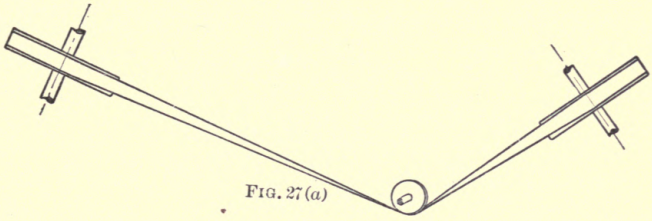


FIG. 27 (*a*)

Belt connection for shafts at angle and on different levels. Belt may run in either direction.

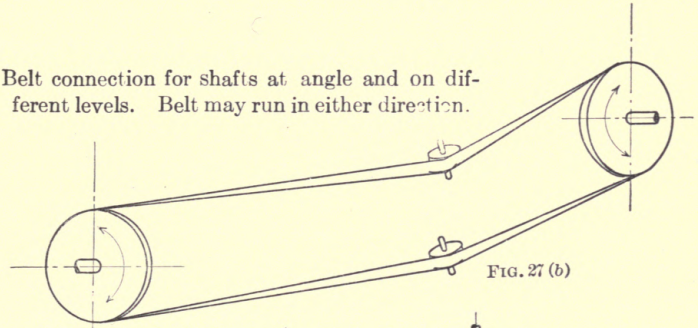


FIG. 27 (*b*)

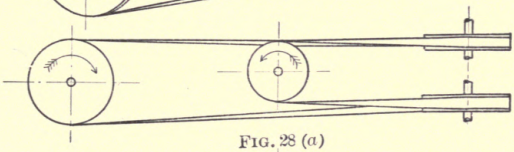


FIG. 28 (*a*)

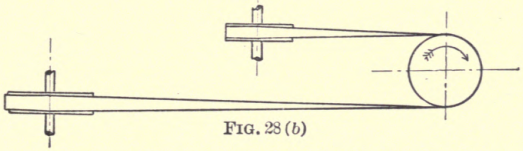


FIG. 28 (*b*)

Belt may run only in direction indicated.

# CHAPTER IV

## TOOTH GEARING

MOTION is transmitted through short distances by means of gears arranged either in a train or connected by link belts. By this method the drive is positive and there is no slip.

**43. Simple Gear Trains.** In this method of gearing the linear velocity of the face of all gears in the train is the same.

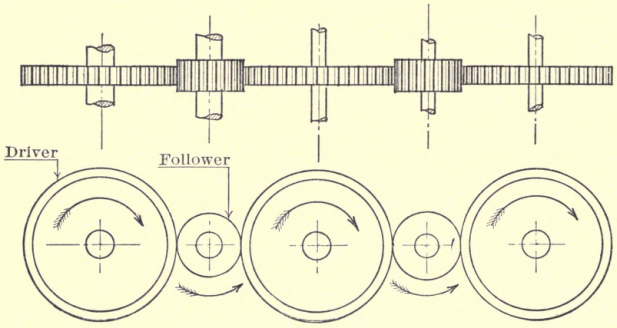



FIG. 29.—Simple Gear Train.

From Fig. 29 it is seen that:

1. In a simple gear train the following gear rotates in the opposite direction to the driving gear.
2. Every second gear rotates in the same direction.

3. In a simple train having an even number of gears the last gear rotates in the opposite direction to the first gear.

4. If there is an odd number of gears in the train the last gear rotates in the same direction as the first gear.

**44. General Rule for Speeds of Gears Arranged in Simple Train.** To find the number of revolutions of any gear for one revolution of any other gear, in a simple gear train, divide the teeth in the first mentioned gear by the teeth in the last.

### PROBLEMS ON SIMPLE GEAR TRAINS

1. Four rolls are connected by gears in the following order: 120 teeth, 100 teeth, 80 teeth, and 60 teeth. Give the direction and turns of each roll per minute, if the 120-tooth gear turns right-handed at 40 R.P.M.

2. A 110-tooth gear drives two 42-tooth gears on the end of feed rolls, the second 42-tooth gear in turn drives two 36-tooth gears on the end of two other rolls. If the first driving gear turns left-handed at 30 R.P.M., give the R.P.M. of the other rolls and the direction of the feed.

3. Give the direction and R.P.M. of a set of gears in a feed mechanism arranged in a simple gear train as follows, the first gear driving left-handed at 40 R.P.M.: 84 teeth, 22 teeth, 22 teeth, 84 teeth, 20 teeth, 84 teeth, 18 teeth, 13 teeth.

**45. Compound Gear Trains.** To reduce or to increase the speed in gear trains, the gears are arranged in compound as illustrated in Fig. 30. By this arrangement a driving gear fixed with the first driven gear drives a second driven gear which in turn may have a driving gear operating as in the first set.

*The revolutions of the last gear in the train for one of the first are found by multiplying together the teeth on the driving*

*gears and dividing this by the product of the teeth on the driven gears.*

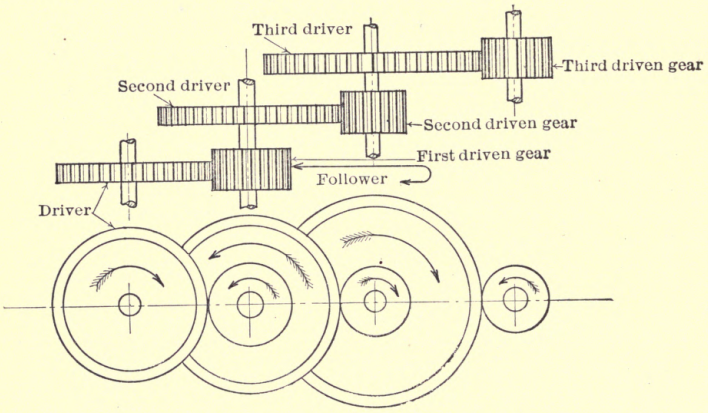



FIG. 30.—Compound Gear Train.

## PROBLEMS ON COMPOUND GEAR TRAINS

1. In the gear train, Fig. 31, give the direction and revolution of last gear for one of the first.

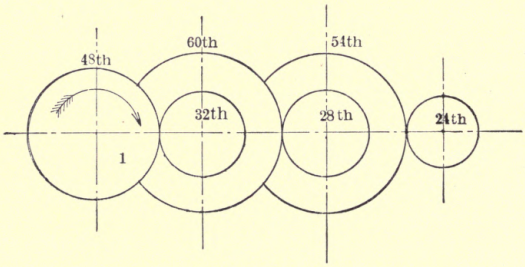



FIG. 31.

2. Find the R.P.M. and direction of the last roll for the train of Fig. 32 if first roll makes 42 R.P.M. and turns right-handed.

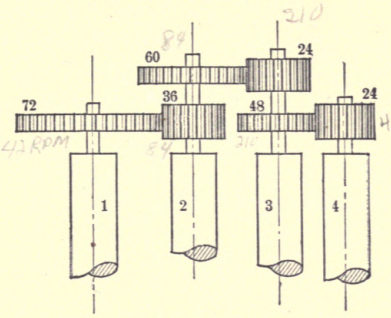



FIG. 32.

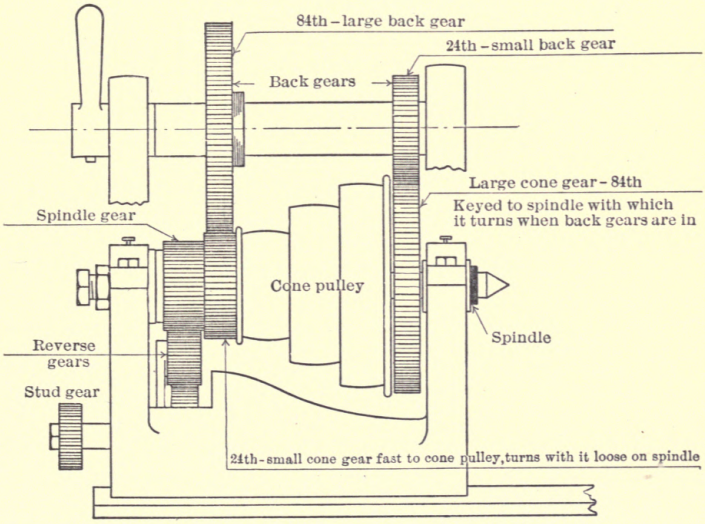

84th – large back gear
24th – small back gear
Back gears
Large cone gear – 84th
Keyed to spindle with which it turns when back gears are in
Spindle gear
Cone pulley
Spindle
Reverse gears
Stud gear
24th – small cone gear fast to cone pulley, turns with it loose on spindle

FIG. 33.—Head Stock Gearing Showing Arrangement of Back Gears.

NOTE. Cone pulley which is driven by belt runs free on spindle, turning with it the small cone gear. The driving takes place through small cone gear, large back gear, small back gear, and large cone gear to spindle, which turns spindle gear keyed to it and drives through reverse gear to stud gear, then to lead screw.

3. In the back-gear train on a 10″ lathe shown in Fig. 33, how many turns does the spindle make for 100 revolutions of the cone pulley?

4. Make a sketch of the hoisting machine in Fig. 34, and find the number of turns of the handle required for one of the drum. How many times must the handle turn around to raise a weight 10 ft.? The diameter of the drum is 8″.

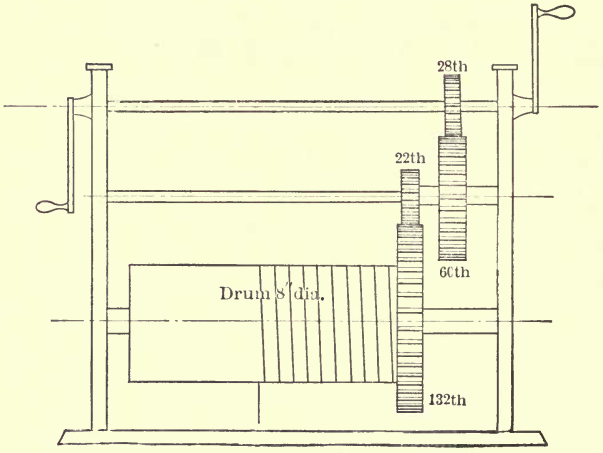



Fig. 34.—Hoisting Machine.

5. Prove that the arrangement of gears in a clock, Fig. 35, is correct.

6. Arrange another set of gears for a similar clock and prove that they are correct.

7. Make a sketch of the apron gears and cross-feed screw used in the power cross-feed on an engine lathe, as in Fig. 36.

How far will the tool move in taking a cross-feed cut during 40 turns of lead screw? What is the rate of travel of the cross-feed? How far will the tool travel in 75 turns of lead screw?

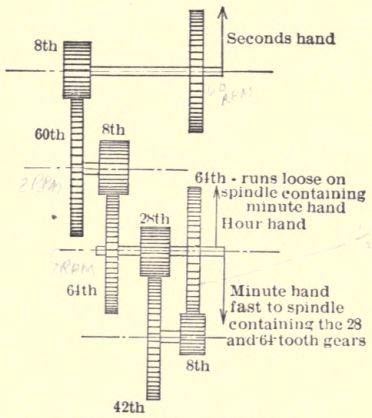



FIG. 35.—Clock Gears.

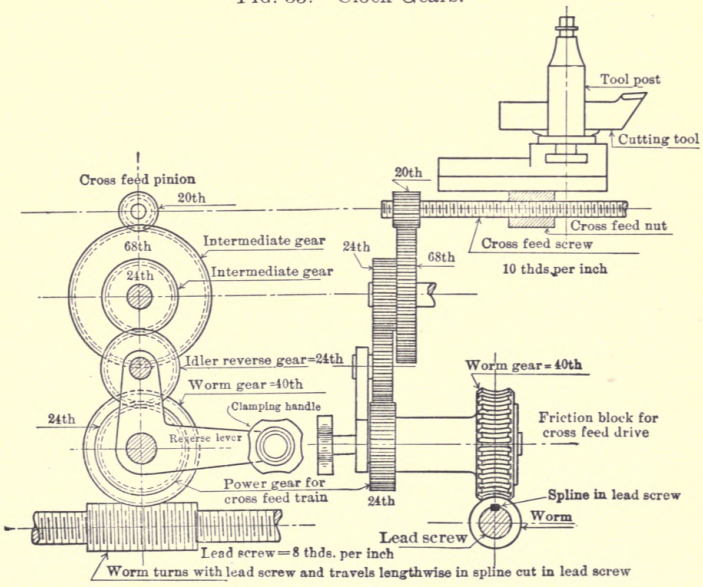



FIG. 36.—Gear Train in Power Cross-feed of a 14″ Engine Lathe.

8. In the cross-feed mechanism, Fig. 37, what is the rate of

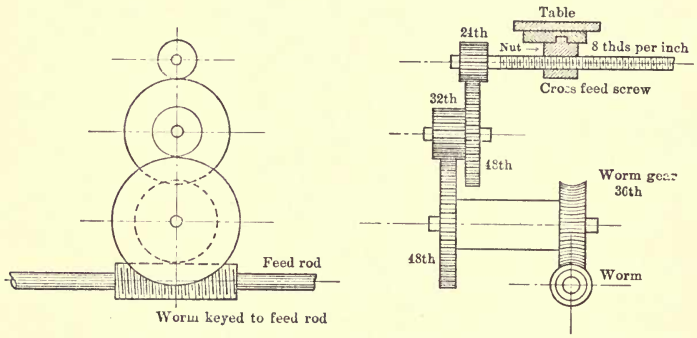



FIG. 37.—Cross-feed Mechanism.

travel of the cross-feed? How far will the table travel during 12 turns of the feed rod?

**46. Simple Gearing as Applied to a Lathe.** Fig. 38 shows the arrangement of gears in a lathe. The idlers used do not effect the velocities of the gears, but only serve to reverse the motion of the following gear.

In the illustration the drive is as follows: With the back gears in, gear No. 1 is fast to the cone pulley and turns with it loose on the spindle, driving through the back gears No. 2 and No. 3 to gear No. 4, which is keyed to the spindle but unlocked from cone pulley. The spindle gear turns with the spindle and drives the inside stud gear through an idler, turning the change stud gear, which drives through idler to the lead screw.

When the back gears are out, gear No. 4 is fastened by a pin to the cone pulley and turns with it, and the rest of the driving is the same as before.

**47. Rule.** *To find the turns that the lead-screw makes for one of the spindle, multiply the teeth in the spindle gear*

*by the teeth in the change stud gear, and divide this by the product of the inside stud gear and the lead-screw gear. In*

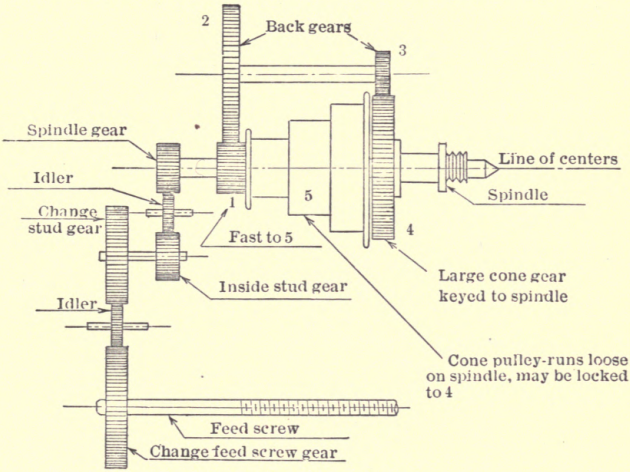



FIG. 38.—Lathe Gears.

*case the spindle gear and the inside stud gears are the same, divide the stud gear by the lead-screw gear.*

## PROBLEMS

1. The spindle gear on a simple-geared lathe has 24 teeth, the inside gear on the stud 24 teeth, the change stud gear 16 teeth, and the lead-screw gear 80 teeth. How many turns does the spindle make for one of lead screw?

NOTE. The rule by which such a case is worked out is the inverse of the rule above and is much the same as the one expressed under the head of "Compound Gear Trains." It may be written: Turns of spindle for one of lead screw equals

$$\frac{\text{Lead-screw gear} \times \text{inside gear}}{\text{Change stud gear} \times \text{spindle gear}}$$

*Solution of Problem No. 1,*

$$\frac{80\times24}{16\times24}=5 \text{ turns of spindle for 1 of lead screw.}$$

2. A lathe having the spindle gear and inside gear of same size has a 32-tooth stud gear and a 72-tooth gear on the lead screw. How many turns does the spindle make while the lead-screw gear turns once?

3. On a small screw-cutting lathe the gears are arranged as follows: spindle gear 32 teeth, inside gear 24 teeth, change stud gear 32 teeth, lead-screw gear 40 teeth. How many turns does the spindle make while the lead-screw gear turns once?

4. In order to obtain two turns of a spindle for one of lead screw when a 48-tooth gear is used on the lead screw, and the inside gears are alike, what size gear must be used on the stud?

NOTE. This may be solved by a rule which is a form of the rule previously given.

Change gear on stud equals

$$\frac{\text{Lead-screw gear}}{\text{Turns of spindle for one of lead screw}}.$$

5. On a simple-geared lathe the operator on a special job finds it necessary to have the spindle make 2 turns while the lead screw makes 3 turns. What gear must be used on the stud if a 36-tooth gear is used on the lead screw?

6. To change the lathe in the above question so as to have the spindle make 3 turns for 2 of the lead screw, what gear must be used on the lead screw if a 48-tooth gear is used on the stud?

NOTE. The rule applying to this case is a form of the rule previously stated:

$$\text{Lead-screw gear}=\frac{\text{Turns of spindle}\times\text{stud gear}}{\text{Turns of lead screw}}.$$

7. The change lead-screw gear has 32 teeth while the outside stud gear has 40 teeth. If both the spindle gear and the inside stud gear have the same number of teeth, how many turns will the lead screw make while the spindle turns once?

8. How many turns of lead screw for one turn of the spindle

when spindle gear has 24 teeth, inside stud gear 32 teeth, outside change stud gear 48 teeth and the lead-screw gear 24 teeth?

**48. To Find the Threads Cut per Inch on a Simple-geared Lathe.**

NOTE. As the spindle gear and the inside stud gear are most always the same size they are not to be considered in the following work, hence not in the rule here given.

*Threads cut per inch on simple-geared lathe equal*

$$\frac{\textit{Threads on lead screw} \times \textit{teeth on lead-screw gear}}{\textit{Teeth on stud gear}}.$$

**PROBLEMS**

1. On a simple-geared lathe having 6 threads to the inch on the lead screw, how many threads are cut per inch when a 32-tooth gear is used on the stud and a 96-tooth gear is used on the lead screw?

*Solution.* $\frac{96 \times 6}{32} = 18$ threads cut per inch.

2. Using an 80-tooth gear on the lead screw and a 16-tooth gear on the stud, how many threads may be cut per inch where the lead screw has 8 threads per inch?

3. A lathe having a lead screw with 6 threads per inch running simple-geared, uses a 32-tooth gear on the stud and a 48-tooth gear on the lead screw. How many threads are cut per inch with this combination?

4. What gear must be used on the lead screw in order to cut 8 threads per inch when the lead screw has 6 threads per inch and a 48-tooth gear is used on the stud?

NOTE. The rule applying in this case is a form of the one previously expressed regarding thread cutting.

Gear on lead screw equals

$$\frac{\text{Threads to be cut} \times \text{teeth in stud gear}}{\text{Threads on lead screw}}.$$

5. What gear must be placed on the stud to cut 14 threads

per inch when a 56-tooth gear is used on the lead screw and there are 6 threads per inch on lead screw?

NOTE. This rule is a form of the above, expressed as follows: Gear on stud equals

$$\frac{\text{Threads on lead screw} \times \text{teeth in lead-screw gear}}{\text{Threads to be cut}}.$$

**49. Gear Combinations to Cut any Special Thread.** To find the combination of gears to cut any desired thread on a simple-geared lathe, select gears that bear the same proportions to each other as the threads to be cut bear to the threads per inch on the lead screw.

This method of calculation is derived from the general rule on thread-cutting and may be expressed in a ratio form as below:

$$\frac{\textit{Lead-screw gear}}{\textit{Stud gear}} = \frac{\textit{Threads to be cut per inch}}{\textit{Threads per inch on lead screw}}.$$

EXAMPLE SHOWING HOW TO FIND COMBINATION TO CUT A SPECIAL THREAD ON A SIMPLE-GEARED LATHE. What pair of gears may be used to cut $4\frac{1}{2}$ threads on a lathe having 6 threads on lead screw?

*Solution.* Ratio of gears $= \frac{4\frac{1}{2}}{6} = \frac{\frac{9}{2}}{6}$ or $\frac{9}{12}$.

Any two gears having the relation of 9 to 12, which is the same as 3 to 4, may be used. 48 and 64 will answer, or 36 and 48, or 60 and 80.

To prove that $4\frac{1}{2}$ threads can be cut where a 48 gear is used on the lead screw and 64 on the stud, and where there are 6 threads per inch on the lead screw, use the rule relating to thread-cutting as given on page 49.

PROOF. $\frac{6 \times 48}{64} = \frac{36}{8} = 4\frac{1}{2}$ threads cut per inch.

### PROBLEMS

1. On a simple-geared lathe with 6 threads on the lead screw, what gears are to be used on the stud and the lead screw to cut $1\frac{1}{2}$ threads per inch?

2. In the above case what gears would be used on a lathe having 4 threads on the lead screw? What gear is used on the stud and what gear on the lead screw?

3. A lathe cutting $6\frac{1}{2}$ threads per inch has a lead screw with 6 threads per inch. What gears may be used, and where?

4. In cutting 2 threads per inch on a lathe having 4 threads per inch on the lead screw, a 32 gear is used on the lead screw. What gear is used on the stud?

RULE. $$\textit{Gear on stud} = \frac{\textit{Lead-screw gear} \times \textit{threads on lead screw}}{\textit{Threads to be cut}}$$

5. If a 32 gear used on the stud, and a 48 gear on the lead screw will cut 4 threads per inch, how many threads are on the lead screw?

RULE. *Threads on lead screw equals*

$$\frac{\textit{Stud gear} \times \textit{threads cut per inch}}{\textit{Lead-screw gear}}.$$

6. Find suitable gears within the range of 16 and 96 to cut the standard threads from 4 to 48, including $11\frac{1}{2}$, when the lathe is simple-geared and a lead screw with 8 threads to inch is used.

**50. Compound Gearing as Applied to a Lathe.** The name " compound " is applied to the method of gearing (shown in Fig. 39) because of the compound gear train through No. 3, No. 4, No. 5 and No. 6.

The driving of the lead screw takes place the same as in the simple-geared lathe.

*To find the turns that the lead screw makes for one of the spindle, multiply the driving gears No. 1, No. 3 and No. 5 together, and divide by the driven gears No. 2, No. 4 and No. 6.*

EXAMPLE. If No. 1 = 24, No. 2 = 24, No. 3 = 32, No. 4 = 72, No. 5 = 36, No. 6 = 48, then the turns of lead screw for one of spindle are, $\frac{24\times32\times36}{24\times72\times48}=\frac{1}{3}$ = turns that lead screw makes for one of spindle.

NOTE. The spindle gear and the inside gear are usually alike, so may not be considered in the following calculations.

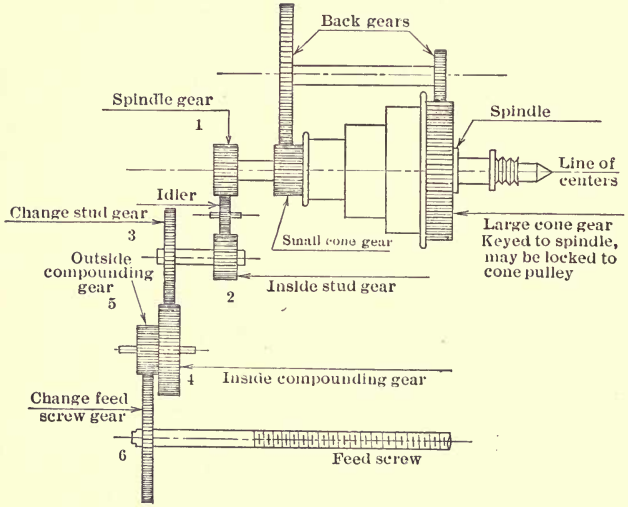



FIG. 39.—Compound Gearing on a Lathe.

## PROBLEMS RELATING TO COMPOUND GEARING OF LATHE

1. Using a 96 gear on the lead screw and a 32 on the stud, with compounding gears 48 and 24, how many times will the spindle turn while the lead screw turns once?

2. With the same compounding gears as above, how many turns will the spindle make when a 36-tooth gear is used on the lead screw and a 48-tooth gear on the stud?

3. In order that the spindle on a certain lathe may make as many turns as the lead screw, what gears may be used?

**51. Threads Cut per Inch.** To find the threads cut per inch on a compound lathe, the rule is the same as in simple gearing except that the gears used in compounding must be considered.

$$\textit{Threads cut per inch on compound geared lathe} = \frac{\textit{Threads on lead screw} \times \textit{lead-screw gear} \times \textit{inside compound gear}}{\textit{Stud gear} \times \textit{outside-compound gear}}$$

EXAMPLE. Find the threads cut per inch when the lead-screw gear is 48, the stud gear 64, and the compounding gears 36 and 72, and there are 8 threads on the lead screw.

*Solution.* $\dfrac{8 \times 48 \times 72}{64 \times 36} = 12$ threads cut per inch.

### PROBLEMS RELATING TO THREAD CUTTING ON A COMPOUND GEARED LATHE

1. Using the same lathe and the compounding gears in the above case and having a 16-stud gear and a 72 lead-screw gear, how many threads are cut per inch?

2. On a lathe having 6 threads per inch on the lead screw with compounding gears 48 and 24, a 64 gear is used on the lead screw and a 32 on the stud. How many threads are cut per inch?

3. How many threads are cut per inch in a lathe having 8 threads on the lead screw and using 48 and 72 for the compound gears, with a 64-tooth gear on the stud and a 32 gear on the lead screw?

4. In the above lathe how many threads will be cut if the stud gear and leadscrew gear were changed about?

5. A lathe having 4 threads per inch on the lead screw, using 36 and 72 as compounding gears, has a 48 gear on the stud and a 92 gear on the lead screw, how many threads are cut?

6. Arrange a suitable gear list for a compound geared lathe to cut from 4 to 72 standard threads, the lead screw having 8 threads per inch.

**52. Use of Different Compound Gears.** Quite often with the ordinary set of change gears the range of thread-

cutting on a compound lathe could be greatly extended if a different set of compound gears was used.

The ratio of these gears can readily be found from the first rule under "Compound gearing on lathe." It is expressed in fraction form as follows:

*Ratio of inside compounding gear to outside compounding gear*

$$= \frac{\textit{Threads to be cut per inch} \times \textit{stud gear}}{\textit{Threads per inch on lead screw} \times \textit{lead-screw gear}}$$

EXAMPLE. On a special threading job it is desired to cut 2 threads per inch. The lead screw on the lathe used has 6 threads per inch, while a 48-tooth gear is used on the stud and a 32-tooth gear on the lead screw. What arrangement of compounding gears is suitable under such conditions?

*Solution.*

| | |
|---|---|
| Threads cut per inch | = 2 |
| Threads on lead screw | = 6 |
| Stud gear | =48 |
| Lead-screw gear | =32 |

Then, $\frac{2 \times 48}{6 \times 32} = \frac{1}{2}$ = ratio of inside gear to outside gear.

That is, with a 24-tooth inside gear a 48-tooth outside gear should be used. Any other two gears with this ratio would also do.

### PROBLEMS INVOLVING FINDING THE RATIO OF COMPOUNDING GEARS

1. A lathe having 8 threads per inch on the lead screw is being set up to cut 23 threads. What suitable compounding gears could be used if the lead-screw gears have 92 teeth and the stud gear 36 teeth?

2. It is desired to cut 64 threads per inch on a lathe having 8 threads per inch on the lead screw. A 16-tooth gear is used on the stud and a 64-tooth gear on lead screw. What two compounding gears could be used?

3. A lathe using a 72-tooth gear on the stud and a 32-tooth

gear on the lead screw, has 6 threads on the lead screw. What compounding gears are used in cutting $1\frac{1}{2}$ threads per inch?

4. What compounding gears are to be used to cut $5\frac{1}{2}$ threads per inch when the lathe has 6 threads per inch and a 44-tooth gear is used on the lead screw and a 32-tooth gear is used on the stud?

**53. Sizes of Stud and Lead-screw Gears.** The size of stud gear and lead-screw gear needed in cutting a desired thread with a given set of compounding gears may also be found from this first rule on "Compounding gearing as applied to the lathe."

$$\textit{The ratio of the stud gear to the lead-screw gear} = \frac{\textit{Inside compound gear} \times \textit{threads on lead screw}}{\textit{Outside compound gear} \times \textit{threads to be cut}}.$$

EXAMPLE. In cutting 5 threads on a lathe having a lead screw with 6 threads per inch and using 48 and 72-tooth gears for compounding, what size gears are to be used on the stud and the lead screw?

*Solution.*

Inside compounding gear = 72
Outside compounding gear = 48
Threads on lead screw = 6
Threads to be cut per inch = 5

$$\frac{72 \times 6}{48 \times 5} = \frac{9}{5} = \text{ratio of stud gear to lead-screw gear.}$$

72-tooth gear on stud and 40-tooth gear on lead screw will answer.

### PROBLEMS INVOLVING THE FINDING OF LEAD-SCREW GEAR AND STUD GEAR FOR GIVEN THREADS TO BE CUT

1. On a lathe having 8 threads per inch on the lead screw and using 36 and 72 as compounding gears,* what gears must be used on the lead screw and on the stud to cut 4 threads per inch?

* In stating the sizes of the compounding gears the outside gear is given first, the inside compounding gear is given second.

2. What gears must be used to cut 12 threads on a lathe having 6 threads per inch on the lead screw where 24 and 48 are used as compounding gears?

3. A certain job requiring a cut of $1\frac{1}{2}$ threads per inch is set up on a lathe having 4 threads per inch on lead screw. What suitable gears can be used on the stud and the lead screw where 24 and 72 are used as compounding gears?

4. Make a complete list of change gears with one set of compounding gears, to be used on a lathe having 8 threads per inch on the lead screw, and cutting from 4 to 48 threads per inch of standard sizes, including $11\frac{1}{2}$. Gears must not be smaller than 16 or greater than 96.

## CHAPTER V

## FORCE AND ITS RELATION TO WORK

**54. Work.** Work is the overcoming of resistance through space. The amount of work performed depends upon the force acting and the distance it acts through, and is expressed in terms of a unit known as the *foot-pound*. This unit signifies the amount of work done in lifting a pound weight through a distance of 1 ft., or the amount of work done in overcoming a resistance of 1 lb. through a distance of 1 ft.

*To find the amount of work done in lifting a body through a given distance, multiply the weight of the body in pounds by the distance moved through in feet.*

*To find the amount of work done in overcoming any given resistance, multiply the force required in pounds (equals the resistance overcome) by the distance moved in feet in the direction of the force.*

From the above it may be seen that the same amount of work may be done in moving a large weight through a small distance, as in moving a small weight through a great distance. For example, as much work is done in lifting 50 lbs. through 10 ft. as in lifting 10 lbs. through 50 ft., or lifting 25 lbs. through 20 ft.; in either case 500 ft.-lbs. of work are done.

To enable work to be done to advantage, different forms of machines and mechanical devices are used, but in none of these can energy be created. The arrangement of the

parts is such as to enable the applied force to be transferred so that it may be used to advantage. If all machines could deliver the same amount of energy that is supplied to them, i.e., if there were no internal losses, the foot-pounds of work input would equal the foot-pounds of work delivered.

This *input*, or the work supplied, would be equal to the applied force multiplied by the distance it moves through, while the *output*, or the work delivered, would be equal to the resistance to be overcome multiplied by the distance moved through. That is, the work done by a small force moving through a great distance would be the equivalent of the work necessary to overcome a greater resistance through a smaller space, or the equivalent of the work necessary to move a large weight through a small distance.

But the work done by a machine is always less than the energy supplied, due to losses in friction, heating, etc. This relation of work done to the energy supplied is an expression of the *efficiency* of the machine, and is commonly stated as the relation of output to input. Efficiency is commonly stated as a per cent. As the losses in a machine become less, its efficiency increases.

In all calculations, unless otherwise stated, we will assume that the work done equals the energy supplied, and express it by the form:

$P \times d_1 = W \times d_2$, where in the case of moving a weight with a certain force;

$P$ = applied force in pounds;

$d_1$ = distance in feet applied force moves through;

$W$ = weight to be lifted or resistance to be overcome;

$d_2$ = distance in feet through which the weight is lifted or the resistance is overcome.

EXAMPLE. A 250-lb. weight on a pile-driving machine is dropped upon a pile from a height of 15 ft. At each fall the pile is driven 3 ins. into the ground. Assuming that none of the energy due to the velocity of the falling weight is lost in overcoming the friction on the slide, what is the resistance offered by the pile? According to the above rule:

250 lbs. $\times$ 15 ft. = 3750 ft.-lbs. = energy supplied in driving pile 3 ins.
3″ (or $\frac{1}{4}$ ft.) $\times$ resistance in pounds overcome = work done or energy expended.

That is $3750 = \frac{1}{4} \times$ resistance in pounds overcome. Reduced to its simplest form this equals 15,000 lbs., the resistance in pounds overcome. This also equals force acting upon the head of the pile.

## PROBLEMS INVOLVING THE USE OF THE WORK FORMULA

1. 132 gallons of sea-water are pumped from the hold of a boat every three minutes. If the lift of the water is 12 ft., how much work is done per hour?

2. In hoisting a timber weighing 324 lbs. 18 ft., how much work is done?

3. A 480-lb. machine mounted upon skids is moved 14 ft. across the shop floor. If the resistance offered to moving is 130 lbs., how much work was done?

4. An apprentice wheeling a truck load of scrap iron 52 ft. performs 2132 foot-pounds of work. How much force is used to move the truck?

5. In driving piles for a foundation, a pile-driver drops a weight of 360 lbs. from a height of 20 ft., driving the pile 4 ins. Assuming that all the energy of the pile-driver is used in driving the pile, what is the force acting upon the head of pile?

6. In lifting a 35-lb. chuck $2\frac{1}{2}$ ft. to a table, how much work is done?

7. On a 4-mile walk, how much work against the wind does a man do if he has to walk against a wind that exerts a pressure of $2\frac{1}{2}$ lbs. per square foot of surface? The surface exposed to the wind may be considered as $4\frac{1}{2}$ sq.ft.

8. By pushing a truck against 42 lbs. resistance for 70 ft., how many foot-pounds of work are done?

9. In punching a hole through a wrought-iron plate $\frac{3}{4}''$ thick the force behind the punch is 62,000 lbs. How much work is done in each operation, assuming that the resistance is uniform throughout?

**55. Levers.** A force is often applied to advantage through the use of links or levers. A *lever* consists of a rigid bar which pivots about a point called the pivot or the *fulcrum*, the position of the pivot determining the advantage of the applied force.

Three arrangements of the force, weight and fulcrum are possible. In all three the following holds true: the

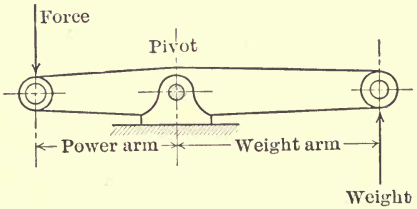



FIG. 40.—Lever; Fulcrum between Force and Weight.

weight arm is the perpendicular distance from the pivot to the weight, and the power arm is the perpendicular distance from the pivot to the point where the force is applied.

In the first arrangement, shown in Fig. 40, the pivot is located between the force and the weight to be moved; the force moves in a direction opposite to that of the weight.

NOTE. In the figure, as also in Figs. 41 and 42, the arrows show the *direction of motion* of the force and the weight.

In the second arrangement, shown in Fig. 41, the pivot is at one end of the lever, and the weight is between the

force and the pivot. The weight and force move in the same direction.

A third arrangement is shown in Fig. 42. The pivot

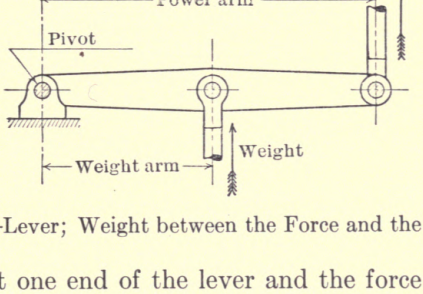



FIG. 41.—Lever; Weight between the Force and the Fulcrum.

is located at one end of the lever and the force and weight move in the same direction.

The same principle applies to levers that applies to all other machines, that is: *The force, multiplied by the dis-*

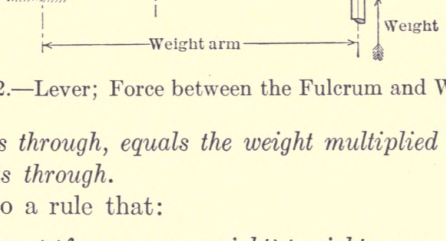



FIG. 42.—Lever; Force between the Fulcrum and Weight.

*tance it acts through, equals the weight multiplied by the distance it acts through.*

It is also a rule that:

$$force \times force\ arm = weight \times weight\ arm.$$

From this rule any one of these four quantities may be found when the other three are known:

(*a*) *To find the force.* Multiply the weight by the weight arm and divide this product by the force arm.

(*b*) *To find the force arm.* Multiply the weight by the weight arm and divide this product by the force.

(*c*) *To find the weight moved.* Multiply the force by the force arm and divide this product by the weight arm.

(*d*) *To find the weight arm.* Multiply the force by the force arm and divide this product by the weight.

From these rules and the illustrations it is seen that the most advantage is gained through the use of a lever of the second arrangement, and a loss in advantage results through the use of a lever of the third arrangement.

The pressure on the pivot in the lever of the arrangement shown in Fig. 40 is found by adding the force and weight together. In the levers of the second and third arrangements, the pressure is equal to the difference between the force and the weight.

## PROBLEMS

1. *Treadle on a foot-power lathe.* Find the direction and amount of the force at *C*, Fig. 43.

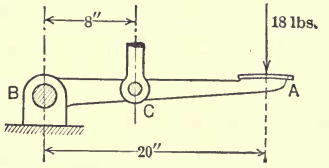



FIG. 43.

2. *Lift rod.* Find the direction and amount of the force at *C*, Fig. 44.

3. *Shoe brake.* Find the amount of the force at $C$, Fig. 45, at right angles to the arm $CB$.

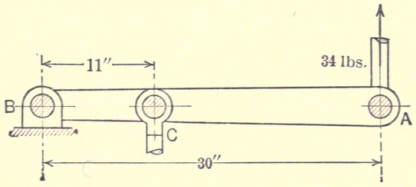



FIG. 44.

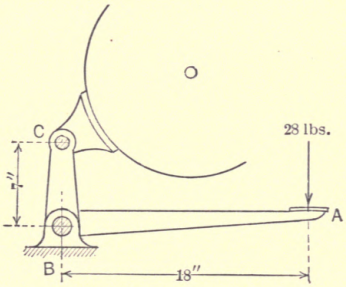



FIG. 45.

4. *Punch rod.* Find the direction and amount of the thrust at $B$, Fig. 46, necessary to exert a force of 600 lbs. at $A$. To which arrangement of levers does this belong?

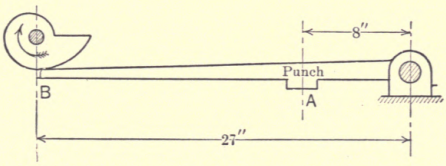



FIG. 46.

5. If in a rod similar to the above a force of 90 lbs. at $B$ gives a resulting force of 540 lbs. at the punch, what is the proportion of the arms? Sketch such a leverage.

6. *Treadle.* Find the force at $C$, Fig. 47, and indicate its direction.

7. If the weight arm in Fig. 47 were 9″, what would be the pressure necessary in order to obtain the same force at $C$?

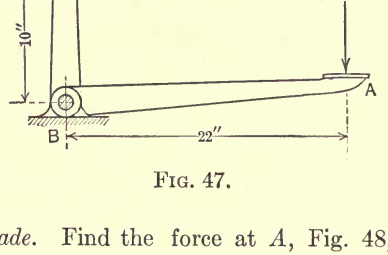



FIG. 47.

8. *Shear blade.* Find the force at $A$, Fig. 48, and indicate its direction.

9. To obtain the same force in the above case with a pressure of 50 lbs., what must be the distance from the center of the blade to the point where the force is applied?

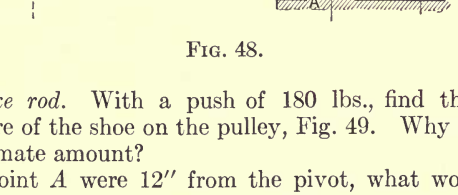



FIG. 48.

10. *Brake rod.* With a push of 180 lbs., find the *approximate* pressure of the shoe on the pulley, Fig. 49. Why is this only the approximate amount?

If the point $A$ were 12″ from the pivot, what would be the push to give the same pressure as above?

11. *Punch rod.* In order to obtain an upward pressure of 200 at $A$, Fig. 50, what must be the force exerted by the cam?

12. If the punch in the above example is moved 2″ to the right, what will be the pressure if the cam exerts the same force as before?

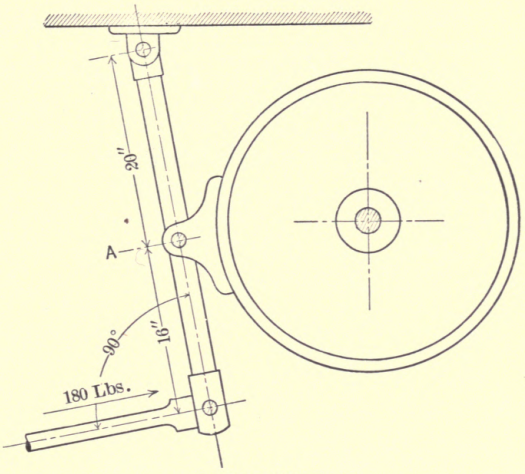



FIG. 49.

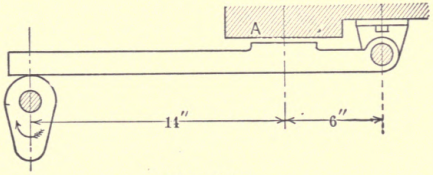



FIG. 50.

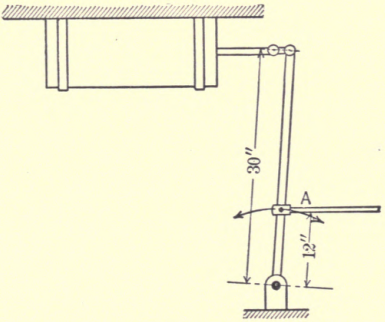



FIG. 51.

13. Air in the air cylinder, Fig. 51, exerts a pressure of 35 lbs. per square inch. The air piston is $5\frac{3}{8}''$ diameter, piston rod is $\frac{3}{4}''$ in diameter. Find the forward and backward thrust at $A$.

**56. Pulley Blocks.** Among the simple machines, the same principle previously stated holds true, that, provided there is no internal loss, *the applied force multiplied by the distance it moves through equals the weight moved multiplied by the distance it moves through.*

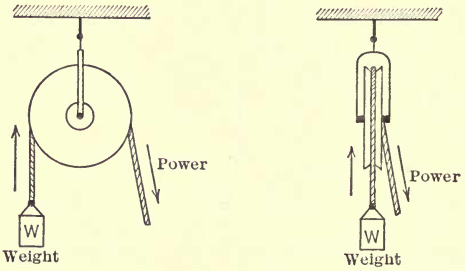



FIG. 52.—Single Pulley.

In a single pulley, as illustrated in Fig. 52, the weight and the power move through the same distance. These pulleys require a force equal to the weight to be lifted, and no advantage is gained in the resulting pull other than a change in direction.

In an arrangement of double pulleys, Fig. 53, in order for the weight $W$ to move through 1 ft. it is necessary for the applied force $P$ to move through 2 ft. That would make $P \times 2d = W \times d$, where $d$ equals the distance the weight moves through. From this $W = 2P$, and the mechanical advantage is 2 to 1.

EXAMPLE. How many pounds may be lifted with a double-pulley block when a pull of 32 lbs. is exerted?

*Solution.* In a double-pulley block the applied force moves through twice the distance that the weight does and the mechanical advantage is 2 to 1. Therefore the weight lifted will be $32 \times 2$ or 64 lbs., assuming there is no loss due to friction.

If a block with *several pulleys* is used, as in the case of a tackle with two sheaves, Fig. 54, it is seen by inspection

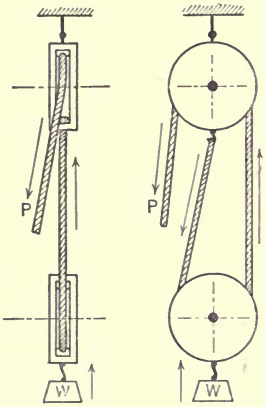



FIG. 53.—Double Pulley.

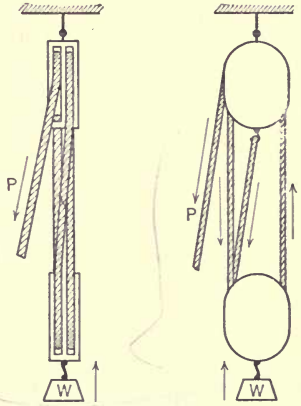



FIG. 54.—Block and Tackle.

that for $W$ to be raised through 1 ft. the applied force must move through 4 ft. A two-sheave pulley is the equivalent of 2 double pulleys placed side by side.

EXAMPLE. In a pair of blocks with two sheaves each, how much weight can be lifted by 22 lbs. pull?

*Solution.* In a block with two sheaves it will be seen that the power moves through 4 times the distance that the weight does, or $P \times 4d = W \times d$. Here the mechanical advantage is 4 to 1. Hence, weight $= 22 \times 4 = 88$ lbs. that may be lifted, disregarding friction losses.

From the above the following general rule may be given:

*The weight lifted is always as many times greater than the applied force as there are supporting cords to the lower set of pulleys.*

### PROBLEMS RELATING TO THE USE OF HOISTING PULLEYS

1. How much force must be exerted upon a weight of 120 lbs. to raise it 4 ft., using a double-pulley block with single sheaves, as in Fig. 53?

2. A bar of iron weighing 420 lbs. is lifted by a double-pulley block with two pulleys in each block. The pulleys offer a resistance of 12 per cent. If two men are put on the job, what pull must each exert to raise the bar?

3. An arrangement of two pulley blocks containing two sheaves, each is used to lift a box of tools weighing 160 lbs. from the floor to the bench, a distance of $2\frac{1}{2}$ ft. How much pull must be exerted? How many feet of rope leave the last sheave?

4. A tackle with two 6″ pulleys in each block is hooked into a casting weighing 240 lbs. How much pull on the rope is necessary in order to raise the casting? How much rope is hauled in in raising it 4 ft. from floor?

5. A 1200-lb. machine is raised by a tackle of two single-pulley blocks. If each block weighs 12 lbs. and a 2″ hemp rope is used, what is the pull required to raise the machine, neglecting friction? What is the pull per square inch area of cross-section of the rope?

6. If in the above problem the lower block is the movable one and the end of the rope is fastened to the upper block, what is the pull on the bolt holding the upper block in place?

**57. The Differential Hoisting Block.** In the *differential hoisting block* the solution depends upon the determination of the distances that the applied force and the weight move through. In one turn of the upper pulley, the power moves through $2 \times R_2 \times 3.1416$ (the circumference of the large pulley). While $B$ moves down $2 \times R_1 \times 3.1416$

(the circumference of the small pulley), $A$ moves up $2\times R_2\times 3.1416$. Since $R_2$ is greater than $R_1$, $W$ moves up $\frac{1}{2}(2\times R_2\times 3.1416 - 2\times R_1\times 3.1416)$ or $3.1416(R_2-R_1)$.

That is, while the applied pull ($P$) moves through $2\times R_2\times 3.1416$, $W$ moves through $\frac{1}{2}(2\times R_2\times 3.1416 - 2\times R_1\times 3.1416)$.

Hence, $P\times 2\times R_2\times 3.1416 = W\times 3.1416(R_2-R_1)$, which states that the power multiplied by the distance it moves through equals weight multiplied by the distance it moves through.

From this equation, $P$ or $W$ may be found when the other is known.

$$P=\frac{W\times(R_2-R_1)}{2R_2} \quad \text{or} \quad W=\frac{P\times 2\times R_2}{R_2-R_1}.$$

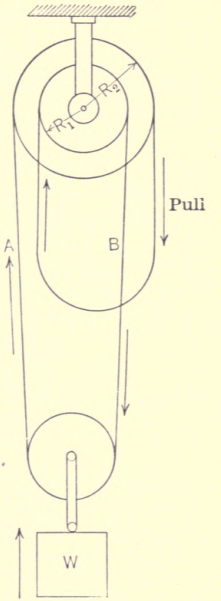



FIG. 55.
Differential Block.

EXAMPLE. To raise a 120-lb. casting 30″ to the work table, a differential pulley block having pulleys 9″ and 6″ in diameter is used. Neglecting the friction, how many pounds pull are necessary?

*Solution.* From the preceding rule,

$$P=\frac{W\times(R_2-R_1)}{2R_2};$$

$$W=120 \text{ lbs.};$$

$$R_2=\tfrac{9}{2}=4.5;$$

$$R_1=\tfrac{6}{2}=3;$$

$$\text{Pull}=\frac{120\times(4.5-3)}{2\times 4.5}$$

$$=\frac{120\times 1.5}{9}=20 \text{ lbs. pull necessary to raise weight of 120 lbs.}$$

## PROBLEMS INVOLVING THE USE OF THE DIFFERENTIAL PULLEY

1. In a differential block with pulleys 8″ and 12″ in diameter, a pull of 38 lbs. is needed to lift a weight of 200 lbs. How much force is used up in overcoming friction?

2. How many feet of rope are unwound from a differential block with pulleys 6″ and 10″ in diameter, in lifting a 240-lb. timber 8 ft.? If the friction is 10 per cent of the weight lifted, how much pull is required? What is the strain on the eye-bolt holding the block in place?

3. To move a 700-lb. speed lathe 8″ along the floor a differential pulley, having pulleys 12″ and 9″, was fastened to a vertical column on a level with the bed, and the lower pulley hooked into the bed. If the resistance to be overcome equaled the total weight of the machine, how much pull was necessary to move the machine? What was the force acting on the column? How much chain was unwound in the 8″ through which the machine was moved?

4. Using a differential block with pulleys 12″ and 8″ in diameter, what pull is needed to raise a 150-lb. casting where there is a friction loss of 20 per cent?

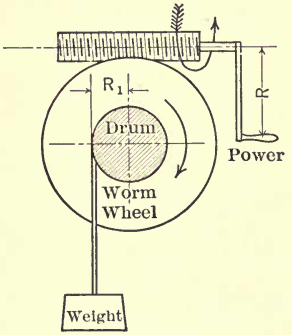



FIG. 56.
Worm and Worm Wheel.

**58. The Worm and Worm Wheel.** In the worm and wheel hoisting apparatus, Fig. 56, the principle is the same as in the pulley blocks. If the worm is single pitch, in order for the worm wheel to revolve once, the handle must be turned as many times as there are teeth in the wheel.

*Then for single-pitch worms,* $P \times 2 \times R \times 3.1416 \times$ *No. teeth in worm wheel* $= W \times 2 \times R_1 \times 3.1416$.

*That is,*

$$P = \frac{R_1 \times W}{R \times No.\ teeth\ on\ worm\ wheel},$$

or

$$W = \frac{P \times R \times No.\ teeth\ on\ worm\ wheel}{R_1}.$$

With any four these items given the fifth may be found.

NOTE. If the worm is double-threaded the worm wheel will move through a distance equal to two teeth with each turn of the handle; if triple-threaded it will move through a distance of three teeth. In either case the number of teeth would have to be divided by the number of threads when the above formulas are used.

EXAMPLE. A single worm and worm wheel arranged for hoisting purposes is operated by a crank arm 16″ long. If the diameter of the drum is 12″ and the worm wheel has 42 teeth, how much force is needed to raise a weight of 350 lbs?

$$\text{Force} = \frac{R_1 \times W}{R \times \text{number teeth in worm wheel}};$$

$$W = 350 \text{ lbs.};$$

$$R_1 = \frac{12''}{2} = 6'';$$

$$R = 16''.$$

Number teeth in worm wheel = 42

$$\text{Force} = \frac{6 \times 350}{16 \times 42} = 3\tfrac{1}{8} \text{ lbs. necessary, neglecting friction losses.}$$

## PROBLEMS INVOLVING THE USE OF WORM AND WHEEL

1. In a worm and wheel arrangement a machine table is rotated about the center of the worm wheel around which the table is built. The worm is single pitch and is operated by a handle 5″ long. If there are 72 teeth in the worm wheel, and the resistance may be taken as 176 lbs., acting 9″ from the axis of rotation, how much force is necessary to operate the table?

2. A hoisting mechanism made up of a worm and wheel is used in raising a weight of 632 lbs. The diameter of the drum is 18″, there are 72 teeth on the worm gear, and the worm, which is operated by an 18″ crank arm, has a $\frac{3}{4}$″ pitch. If 50 per cent of the applied force is wasted in overcoming friction, what force at the end of the crank is needed to raise the weight of 632 lbs.?

**59. The Hoisting Winch.** A *winch* consists of gear wheels used as in Fig. 57 for hoisting purposes. In this,

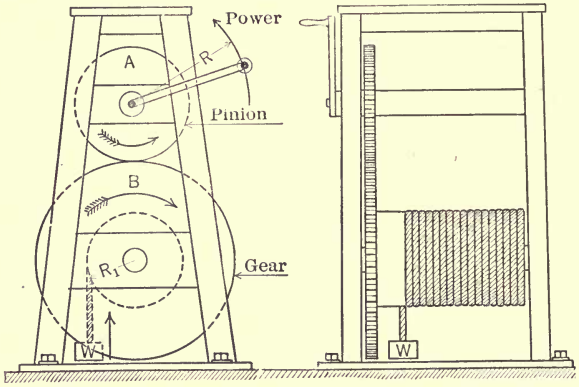



FIG. 57.—Winch.

as in the machines before discussed, the *applied force multiplied by the distance it moves through equals the weight multiplied by the distance it moves through.*

In the winch this is expressed as:

$$P \times 2 \times R \times 3.1416 \times \textit{number of turns of } A \textit{ to one of } B = W \times 2 \times R_1 \times 3.1416;$$

$$\frac{\textit{Teeth on } B}{\textit{Teeth on } A} = \textit{No. of turns of } A \textit{ to one of } B = \frac{\textit{Teeth on gear}}{\textit{Teeth on pinion}}.$$

*That is,*

$$P \times 2 \times R \times 3.1416 \times \frac{teeth\ on\ B}{teeth\ on\ A} = W \times 2 \times R_1 \times 3.1416,$$

*or,*

$$P = \frac{W \times R_1 \times teeth\ on\ A}{R \times teeth\ on\ B},$$

*or,*

$$W = \frac{P \times R \times teeth\ on\ B}{R_1 \times teeth\ on\ A}.$$

EXAMPLE. In a hoisting winch the barrel measures 12″ in diameter and has a gear of 82 teeth. The pinion has 24 teeth and is operated by a handle 18″ long. Assuming that there are no losses in the machine, what weight can be raised by applying a pull of 42 lbs. on the handle?

*Solution.*

$$\text{Weight raised} = \frac{\text{Force} \times \text{radius of handle} \times \text{teeth on gear}}{\text{Radius of drum} \times \text{teeth on pinion}}.$$

| | |
|---|---|
| Force | = 42 lbs |
| Radius of power handle | = 18″ |
| Teeth on gear | = 82; |
| Radius of drum | = 6″; |
| Teeth on pinion | = 24. |

Substituting these in above formula:

$$\text{Weight raised} = \frac{42 \times 18 \times 82}{6 \times 24} = \frac{861}{2} = 430.5 \text{ lbs.}$$

## PROBLEMS ON THE HOISTING WINCH

1. To raise a 588-lb. steel casting a winch having a 21″ handle operating a 28-tooth pinion which engages with a 98-tooth gear is used. The diameter of the drum is 12″. How much pull is needed upon the handle?

2. A hoisting crab with handle 18″ long and a 10″ drum has a 22-tooth pinion and a 124-tooth gear on the drum. The

machine is used to raise a 520-lb. drill press 14 ft. to the second floor of a shop. What pull on the handle is necessary, provided there is no friction loss? If there is a friction loss of 20 per cent, what would be the pull necessary?

3. A 550-lb. girder is raised to position by means of a hoisting machine having a 14″ drum with a 108-tooth gear in mesh with a 20-tooth pinion. The operating handle is 20″ long. Neglecting the friction losses, how much pull on the handle is necessary to raise the girder?

4. An anchor weighing 1000 lbs. is hoisted by means of a capstan which is operated by two men, each pushing at the ends of a $7\frac{1}{2}$-ft. arm. The anchor rope winds on a drum 14″ in diameter. What force is exerted by each man, assuming each pushes the same amount?

5. Referring to the hoist in Problem 2 on page 73, what force acting on an 18″ handle is needed in raising a lathe weighing 1750 lbs., assuming 35 per cent is lost in overcoming friction?

**60. The Jack Screw.** The work formula of the jack screw is the same as that of the other simple machines:*

$P \times 2 \times R \times 3.1416 = W \times$ pitch of screw.

$2 \times R \times 3.1416 =$ the distance the force moves in one turn of the handle.

The pitch of the screw = the distance the weight moves in one turn of handle.

$$\text{Pitch} = \frac{1}{\text{No. threads per inch}};$$

$$W = \frac{P \times 2 \times R \times 3.1416}{\text{Pitch}}$$

$$= \text{No. threads per inch} \times P \times 2 \times R \times 3.1416;$$

*All problems relating to jacks, hand screws, clamping screws, etc., are solved in the same way as those relating to pulleys, proving again that the resulting output of available work is equal to the input, provided there is no loss due to friction, etc. This may be expressed by the statement:

Force applied × distance moved through = available force × distance it moves through.

$$P = \frac{W \times \text{pitch}}{2 \times R \times 3.1416}$$

$$= \frac{W}{\text{No. threads per inch} \times P \times 2 \times R \times 3.1416}.$$

EXAMPLE. A jack screw $\frac{3}{4}''$ single pitch is used in blocking up a machine. If one man operates this jack with a 21-lb. pull upon a 24″ handle, how much is the upward push on the machine if 55 per cent of the applied force is lost in friction?

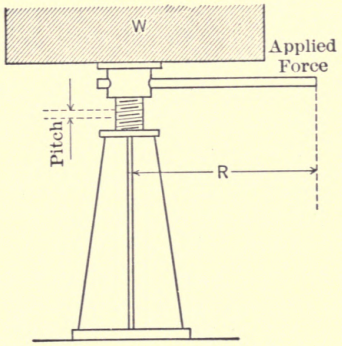



FIG. 58.—The Jack Screw.

*Solution.* In this case the upward push is the equivalent of the weight capable of being lifted.

$$\text{Weight lifted} = \frac{\text{pull} \times 2 \times \text{radius of handle} \times 3.1416}{\text{Pitch}}$$

$$= \frac{21 \times 2 \times 24 \times 3.1416}{\frac{3}{4}}$$

$$= \frac{21 \times 48 \times 3.1416 \times 4}{3} = 4222 \text{ lbs.},$$

neglecting the friction.

If 55 per cent was lost in friction, then this would be reduced by $\frac{55}{100}$, and would be 1900 lbs.

### PROBLEMS INVOLVING USE OF JACK SCREW

1. How many jack screws, each having $\frac{1}{2}''$ pitch and operated by a bar 20″ long, will be required to jack up a building weighing 46 tons, when a pull of 35 lbs. is exerted at the end of the rod, and 60 per cent is assumed as the loss due to friction and other sources?

2. A jack screw having 2 threads per inch is used to raise a load of 1200 lbs. a distance of $1\frac{1}{2}''$. If a bar extending 26″ out from center of the screw is used, what is the necessary pull, allowing 56 per cent for friction?

3. In tightening a nut on a 1″ bolt, a wrench with a 9″ leverage is used. With a pull of 15 lbs., what is the clamping force of the nut, allowing 65 per cent loss for friction?

4. With what force does a bench vise, having a $\frac{1}{4}''$ pitch screw, clamp a piece of work when a pull of 14 lbs. is exerted at the end of a 12″ handle if friction is neglected?

**61. Power.** By *power* is meant the rate at which work is done. Thus a motor which lifts a weight of 1000 lbs. 100 ft. in a minute, does 100,000 ft.-lbs. of work per minute. This is a measure of the power that the motor supplies. Power is commonly expressed in units known as *horse-power* (H.P.). A horse-power is the equivalent of 33,000 ft.-lbs. work done in one minute, or 550 ft.-lbs. per second. In measuring power the time in which the work is done must be considered.

*To find the equivalent horse-power, reduce the foot-pounds of work done in a given time to foot-pounds of work done per minute and divide this by* 33,000.

EXAMPLE. How much work is done per minute by a pump which raises 450 gallons of water per minute from a well 86 ft. deep? What is the equivalent horse-power?

*Solution.* $450 \times 8\frac{1}{3} = 3750$ lbs. = weight of 450 gallons of water;

$3750 \times 86 = 322{,}500$ ft.-lbs. per minute;

$$\frac{322500}{33000} = 9.77 \text{ H.P. equivalent.}$$

### PROBLEMS INVOLVING THE CALCULATION OF HORSE-POWER

1. An engine pumps 310 gallons per minute from a well 28 ft. below the point of delivery of the water. What horse-power is required, assuming 8 per cent loss in piping and pumps?

2. In planing a casting 4 ft. long, the average resistance offered to cutting is 582 lbs. If the planer makes 9 cutting strokes per minute, how much horse-power is being absorbed in the planing operation?

3. A pile-driver weighing 287 lbs. is dropped twice per minute from a height of 12 ft. How much horse-power is required to operate this, assuming 25 per cent loss in friction?

4. A shaper makes 15 cutting strokes per minute over a piece of stock 8″ long. If the average resistance to cutting is 620 lbs., what horse-power is used?

5. In turning up a piece of stock in a lathe, the pressure against the tool is 460 lbs. At a cutting speed of 28 ft. per minute, what horse-power is absorbed?

6. The force exerted by the cutter in milling a casting is 420 lbs. If the cutting speed is 40 ft. per minute, what power is required? How many horse-power?

**62. Horse-power of Belts and Shafting.** In belting it is commonly assumed that a belt running at 1000 ft. per minute delivers 1 H.P. for each inch of width of belt.

A much used value in determining the horse-power of a belt is 35 lbs. pull per inch for single belt, and 60 lbs. pull for double belt. Using this, the horse-power a belt may transmit is found by multiplying the width of the belt by the effective pull per inch, and this product by the velocity of the belt. This, giving the effective foot-pounds per minute, should be divided by 33,000 to change to horse-power.

This may be worked out as follows:

The velocity of the belt = circumference of pulley in

feet×R.P.M., which equals 3.1416×diameter of pulley in feet×R.P.M.

That is, effective pull×3.1416×diameter of pulley in feet×R.P.M. = foot-pounds work per minute.

For a single belt, the horse-power transmitted may be estimated as:

$$\frac{35\times\text{width of belt in ins.}\times 3.1416\times\text{dia. pulley in ins.}\times\text{R.P.M.}}{12\times 33000}$$

Reduced to lowest terms the horse-power for single belts = .000278×diameter of pulley in inches×R.P.M.×width of belt in inches; or, .00048×diameter of pulley in inches×R.P.M.×width of belt in inches for double belts.

### PROBLEMS

1. An 8″ single-ply belt, running at 825 ft. per minute is capable of delivering what horse-power, provided there is no belt loss?

2. What horse-power may be transmitted by a 6″ double belt over a 24″ pulley running at 135 R.P.M.?

3. What size single belt would be used in delivering to a line shaft 7 H.P. from a motor having a 10″ pulley running at 630 R.P.M.?

4. Determine the advisable size of a pulley running at 180 R.P.M. to transmit 12 H.P. with a 5″ double belt.

**63. Horse-power of Steam Engines.** The horse-power of a steam engine may be calculated from the average steam pressure per square inch in the cylinder, the length of stroke, the number of strokes per minute, and the area of the piston in square inches.

Expressed in formula, the horse-power of a steam engine equals:

$$\text{H.P.} = \frac{P\times L\times A\times N}{33000}.$$

Where $P$ = the average pressure of the steam per square inch of piston area throughout the length of stroke;

$L$ = the length of the stroke in feet;

$N$ = the number of working strokes per minute (in single-acting engines this equals the R.P.M.; in double-acting engines it is $2 \times$ R.P.M.);

$A$ = the area of the piston in square inches.

EXAMPLE. What is the horse-power of a single-acting steam engine with a 16″ stroke, a 9″ piston, making 120 R.P.M. with an average steam pressure upon the piston of 40 lbs. per square inch?

Calculated horse-power $= \frac{P \times L \times A \times N}{33000}$;

Area of the piston $= .7854 \times 9 \times 9 = 63.62$ sq.ins.;

Length of stroke in feet $= \frac{16}{12} = 1\frac{1}{3}$ ft.;

Working strokes $= 120$ per minute;

H.P. $= \frac{40 \times 4 \times 63.62 \times 120}{3 \times 33000} = 12.3.$

NOTE. If the efficiency of the machine is concerned, the actual horse-power developed is always more than the delivered horse-power. This difference is due to friction losses of various kinds that enter into the working of the machine.

## PROBLEMS INVOLVING HORSE-POWER CALCULATIONS

1. A double-acting engine runs at 130 R.P.M. under an average steam pressure of 55 lbs. per square inch upon the piston. What is the horse-power developed if the stroke is 24″, the piston measures 18″ in diameter and the piston rod is $1\frac{3}{4}$″ in diameter?

2. A single-acting Westinghouse engine running at 298 R.P.M. shows an average steam pressure upon the piston of 42 lbs. per square inch. The diameter of the piston measures 12″, and the length of the stroke is 12″. What horse-power is developed?

3. An Otto gas engine having one working stroke in every

eight strokes has an average pressure upon the piston of 91.8 lbs. per square inch, running at 230 R.P.M. If the piston measures $11\frac{1}{4}''$ in diameter and the stroke is 18″, how many horse-power are being developed? If the engine is single-acting and is rated at 36 H.P., what per cent of this is being developed?

4. A double-acting steam engine running at 96 R.P.M. has a 28″ stroke and an 18″ piston with 2″ piston rod. With an average pressure of 72 lbs. upon the piston, how many horse-power would be developed?

5. A gas engine running at 275 R.P.M. has a 15″ stroke and a piston 10″ in diameter. How many horse-power are developed when the average pressure in the cylinder is 68 lbs. per square inch and an explosion occurs every 6 revolutions?

# CHAPTER VI

## FORCES

**64. Representation of a Force by Lines.** To describe a force it is necessary to know its magnitude, direction and point of application.

All three of these may be represented by a straight line; the length of the line, drawn to scale, representing the magnitude of the force, one end of the line the point of application, and an arrow head showing the direction.

In Fig. 59 are represented two forces, one of 25 lbs.,

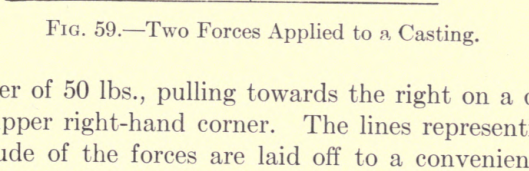



FIG. 59.—Two Forces Applied to a Casting.

the other of 50 lbs., pulling towards the right on a casting, at its upper right-hand corner. The lines representing the magnitude of the forces are laid off to a convenient scale, a certain part of an inch representing a given number of pounds pull. The 50-lb. pull line is thus twice as long as the 25-lb. line.

**65. Reaction.** If two equal and opposite forces in the same straight line are applied to a bar, the piece will remain at rest. If the piece is fastened at one end and subjected to a pull and still remains at rest, there must be an equal

and opposite force acting. The same is true if weights be laid upon a support; if the support remains at rest under the pressure, there must be reacting, equal and opposite forces to resist the downward pressure.

A force cannot act alone when a body is at rest, for there must always be an equal and opposite force to produce the equilibrium. This opposite force is called a reacting force, or the *reaction.*

Where several forces are acting, if the sum of the forces

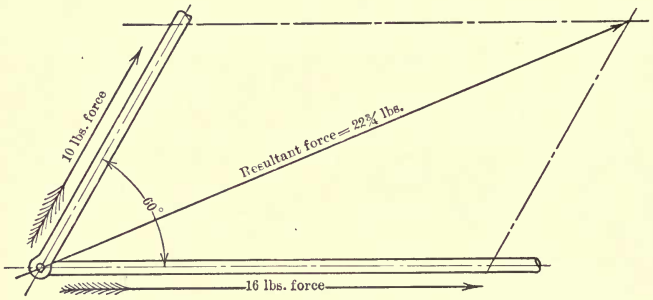



FIG. 60.—The Parallelogram of Forces.

in one direction are not equal to the sum of all the forces in the opposite direction, the body will move in the direction of the greater sum with a force equal to the difference between the sums. This is well illustrated in the game called a "tug of war."

**66. Parallelogram of Forces.** When two forces act at a point but not in a straight line, a single force may be found whose magnitude, direction and point of application will produce the same result as the combination of forces of which it is the equivalent. Such a single force is known as the *resultant.*

These forces are combined as in Fig. 60, the principle being known as the *parallelogram of forces.*

EXAMPLE. A force of 16 lbs. and a force of 10 lbs. act along two links jointed at one end, but spread apart by an angle of 60°, as shown in Fig. 60. What is the magnitude and direction of the resultant force?

*Solution.* Let $\frac{1}{4}''$ represent each pound of force, and lay off from the same point force lines according to the conditions in the problem. One force of 10 lbs. is represented by a line $2\frac{1}{2}''$ long, the other force, 16 lbs. acting at 60° from it, is represented by a line 4″ long.

Complete the parallelogram by drawing a line from the end of each force parallel to the other force. A line drawn from their intersection to the point of application of the original force lines represents the resultant of the combination. This resultant acts in the direction indicated, and, when scaled for its magnitude, is found to equal about $5\frac{11}{16}''$, which, according to the scale chosen, equals $22\frac{3}{4}$ lbs.

**67. Resultant of More than Two Forces.** By means of the parallelogram of forces, the resultant of any number of forces acting in the same plane and at one point may be found as follows: Lay off any two forces acting at the proper angle to a convenient scale and determine their resultant. Combine the resultant of these two with a third force, which is in turn laid off to the same scale in its proper magnitude and direction, then combine the resultant of these with a fourth force, and so on, each resultant being combined with a remaining force until all have been combined. The final resultant is the resultant of all the forces acting. This may be scaled for its magnitude as before.

EXAMPLE. If the forces in a set of movable links act as shown in Fig. 61, what is the direction and amount of the resultant?

*Solution by the parallelogram method.* From point "0" lay

off the three forces acting in the direction as indicated in the drawing of the links, using a scale of 1″ to 10 lbs.

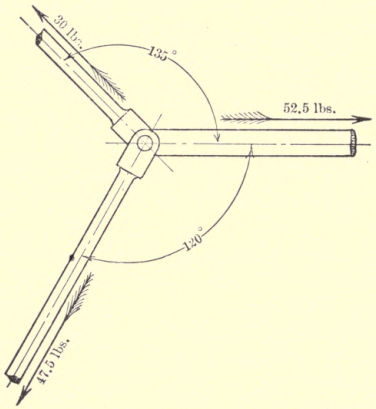



FIG. 61.—Forces in a Set of Movable Links.

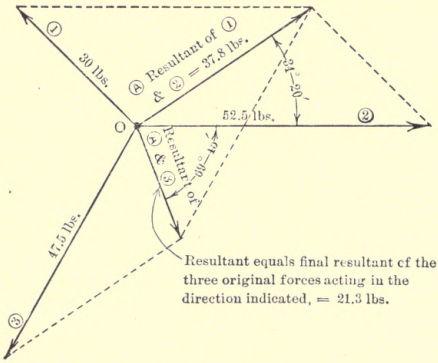



FIG. 62.

According to the parallelogram method, the resultant of forces 1 and 2, when scaled with a rule graduated to 100ths, measures 37.8 lbs., and acts in the direction indicated in Fig. 62. By com-

bining this force of 37.8 lbs. with force 3, a resultant of 21.3 is obtained, acting in the direction indicated. This last force of 21.3 lbs. is the final resultant force of the three original forces 52.5, 30, and 47.5, acting in the different members as indicated.

By using a protractor, the angles at which these resultant forces act may also be noted.

## EXAMPLES TO BE SOLVED BY THE PARALLELOGRAM METHOD.

1. Three tie rods are fastened to a web plate at angles of 45° and 60° apart from left to right, the left rod exerting a pull of

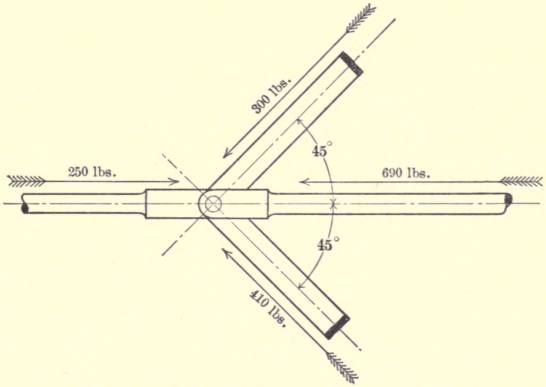



FIG. 63.—Four Forces Acting at a Point.

200 lbs., the right one 150 lbs., the middle rod a pull of 160 lbs. Draw the force diagram, and scale for the value of the resultant, indicating its direction.

2. In hauling a 425-lb. machine which has been placed upon a skid with three ropes, the ropes on each side are at 15° with the center rope. The middle boy pulls with a force of 42 lbs., the boy to his left with a force of 30 lbs., and the one to his right with a force of 56 lbs. Draw the diagram, and find the direction and value of the resultant pull.

3. In Fig. 63, the rods hinge about a bolt pin and are acted upon by the forces as indicated. Determine by graphical method the amount and direction of the resultant force.

4. A simple roof truss has its members 120° apart, the right one carries a thrust of 1200 lbs., the left a thrust of 900 lbs. Show by diagram the direction and magnitude of the resultant.

5. Show by diagram the reactions at the supports of the truss in Problem 4.

6. Two men in pulling a casting along the shop floor by means of two ropes, pull, one in a southwest direction with 30 lbs. force, the other toward the west with a force of 25 lbs. Draw the diagram showing the direction and amount of the combined pulls. How much pull is each man exerting in the direction of the resultant?

**68. Triangle of Forces.** While cases of forces acting at a point can be solved graphically by the parallelogram method, it is sometimes more convenient to solve certain types of problems by what is known as the *triangle of forces*. This method is most clearly applied where one known force is acting and it is desired to find the effect of this force upon the resisting members.

Such a solution is readily used in problems relating to hoisting derricks, wall cranes, toggle joints, weights supported by ropes, or links, that are at an angle with each other.

Example. In the wall crane shown in Fig. 64 (*a*) a 100-lb. weight is suspended at *C*. Find the stress in each member of the crane.

*Solution.* Lay off to some convenient scale, say $\frac{1}{8}''$ for each 10 lbs., a vertical line, as in Fig. 64 (*b*), representing the vertical acting force of 100 lbs. This line will measure, according to the scale chosen, $1\frac{1}{4}''$. Indicate the direction of its action by an arrow line pointing downward, and label the line *XY*. From one end of this line draw a line in a direction parallel to that of the sloping member *AC*. From the other end of the vertical line draw a line parallel to the horizontal direction of member *BC*. These lines

will intersect at the point $Z$. Scale $XZ$ for its value. The line $XZ$ is found to measure $2\frac{1}{2}''$ or 20 eighths. Since each eighth is the equivalent of 10 lbs., $XZ$ represents 200 lbs., the stress acting in the member $AC$. Scaling $YZ$, it is found to equal about $2\frac{1}{8}''$ or 17 eighths. This is the equivalent of 170 lbs. and is the stress in the horizontal member $BC$.

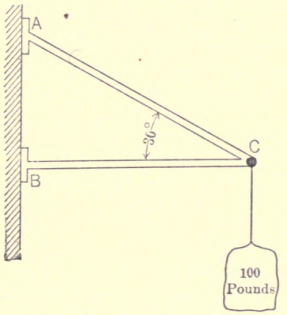



FIG. 64*a*.—Wall Crane.

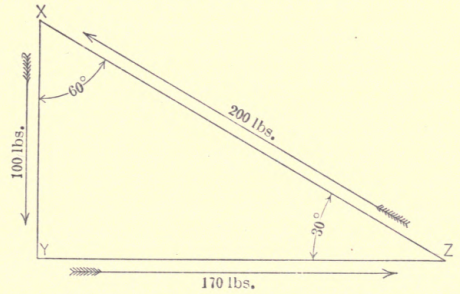



FIG. 64*b*.—Graphical Solution for Forces in a Wall Crane.

Besides giving the *value* of the forces acting in each member, this method may be used to determine the *direction* of the acting forces. This is accomplished by drawing arrow lines around the triangle, the direction of the arrow being obtained from the known direction of the acting

force. The direction of the forces should form a complete circuit.

From the direction of the acting forces it is seen that the resisting force of 200 lbs. in the member $AC$ is a tensile stress, and the resisting force of 170 lbs. in the member $BC$ is a compressive stress.

NOTE. The above problem may also be worked out by the parallelogram method by considering 100 lbs. as the resultant of two forces acting in the direction $CA$ and $BC$. The parallelogram should be drawn, using the line representing 100 lbs. as the diagonal, and completing the parallelogram upon this diagonal. By scaling the sides, the results will check with the above solution.

### PROBLEMS TO BE SOLVED GRAPHICALLY BY THE TRIANGLE METHOD

1. A machine weighing 840 lbs. is supported by two pulley blocks, the angle between the lines of pull in the two blocks is 60°. Find by diagram the pull on each block.

2. A thrust of 90 lbs. is exerted vertically downward upon a toggle joint whose links act at 30° with the horizontal upon a block which slides horizontally. Draw the force diagram and find the direct push upon the block.

3. In pulling a load over a horizontal surface the direction of the pull of 72 lbs. is at an angle of 20° to the surface. Show by diagram the equivalent direct forward pull.

4. A casting weighing 480 lbs. is lifted by two tackle blocks, the ropes slanting 20° and 15° from the vertical. What is the tension in each rope?

5. To raise a machine weighing 220 lbs. two ropes are attached, one pulling upward at 30° from the vertical, the other at 15° from the vertical. Draw the diagram showing the pull on each rope. How much pull does each rope exert in a vertical direction?

**69. Moment of Force.** The moment of a force acting on a body is its tendency to turn the body about some

fixed point as an axis. The value of the moment of a given force with respect to a given axis is equal to the product of the force by the perpendicular distance from the fixed point about which turning occurs to the action line of the force. For example, if a 160-lb. man stood at one end of an 8-ft. plank which was supported only at the other end, there would be a tendency for the weight to move down-

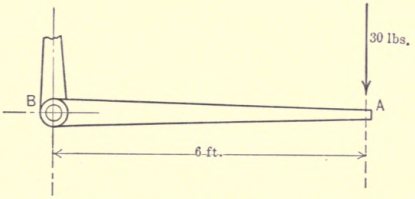



FIG. 65*a*.—Positive Moment.

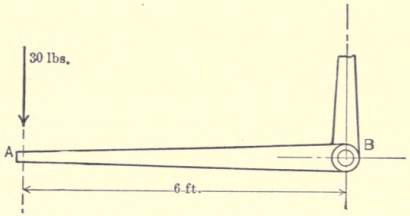



FIG. 65*b*.—Negative Moment.

ward, using the fixed point as the center about which the board would move. The equivalent of the turning moment would be $8 \times 160$, or 1280 lb.-ft.

If the force has a tendency to turn the body in a right-handed direction, the moment is referred to as a *positive moment*, and is indicated by the plus sign before the product representing the value of the moment. If the turning is left-handed, the moment is *negative*, and is repre-

sented by the minus sign before the number representing the product.

Fig. 65 (*a*) represents a case of a positive moment of the force of 30 lbs. about the pin *B*. $6 \times 30 = +180$ lb.-ft. turning moment. The + sign before the product indicates that the turning is right-handed.

Fig. 65 (*b*) represents a negative moment of the force 30 lbs. with respect to an axis at *B*. $6 \times 30 = -180$ lb.-ft. turning moment. The negative sign indicates that the rotation is left-handed.

If the plus moments equal the negative moments, there will be no tendency to turn at the fixed point, and the piece will be in **equilibrium.**

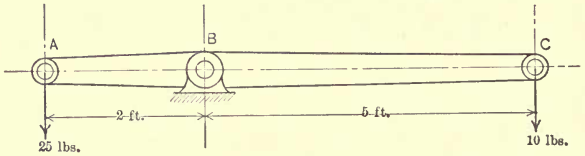



Fig. 66.—Moments Equal About the Axis B.

For two moments to be equal and opposite it is not necessary that the acting forces be equal. So long as the *products* of the force and perpendicular distance are equal, the moments are equal.

Taking moments about the pivot of the rod shown in Fig. 66, and neglecting its weight, it is found that the plus moment, $5 \times 10$, or 50, equals the minus moment of $2 \times 25$. In this case the forces acting are unequal yet the moments are equal. Because of this the bar is at rest.

If the weight on the right end be made heavier that end of the bar will drop, since the moments will not be equal and the bar will not be in equilibrium. If the weight

on the left end be increased that end will drop, and the same conditions would be true.

*If the sum of the moments of all the forces acting about a given point is equal to zero, the body is in equilibrium and there is no tendency to rotate.*

To prove this true, drive a nail through a board fastening it to a vertical surface. In several places attach to the board known weights; these may be pieces of lead which can be nailed on. Spin the board around the nail allowing it to find its own equilibrium.

Knowing the weights attached to the board, find the moment of each about the nail, including the moment of the weight of the board itself. When the board is in equilibrium it will be found that the positive moments equal the negative moments.

This may be repeated by placing the pivoting nail in a different position and finding the moments as before.

### PROBLEMS

1. A beam projecting 6 ft. from the wall has fastened at its end a pulley used for hoisting. What is the turning moment at the point where the beam joins the wall due to hoisting a load of 123 lbs.?

2. A crow bar 4 ft. long is used to jack up a weight by sliding a block in at the bottom and bearing down on the bar. When the block is $\frac{1}{2}$ ft. from the end, a man bears down with a force of 155 lbs. What is the turning moment?

3. A foot lever extending out $2\frac{1}{2}$ ft. from the pivot, is pressed upon with a force of 32 lbs. What is the turning effort?

4. A cam acts on a punch rod with a force of 285 lbs. If the cam bears on the rod at a point $3\frac{1}{4}$ ft. from its pivot, what is the resulting turning effort?

**70. Beams.** Beam problems are solved by making use of the principle of moments. The following problem

will illustrate the method of solving the more simple problems in beams, especially those dealing with the reaction at the supports:

Let a beam 10 ft. long* be supported at each end and have a 50-lb. force acting vertically downward 4 ft. from the right end, as in Fig. 67. So long as the beam is in equilibrium, the sum of the supporting forces must not be less than, nor greater than, the downward forces due to the load. Also the sum of the moments about any point must be

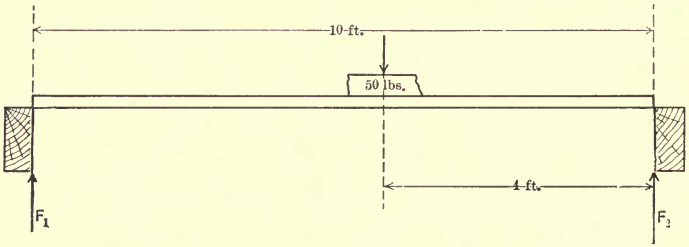



FIG. 67.—Loaded Beam.

equal to zero. That is, the sum of the negative moments must be equal to the sum of the positive moments.

Neglecting the weight of the beam and taking moments about the right end, calling the left supporting force $F_1$ and the right supporting force $F_2$, we have that,

$4 \times 50$ = negative moment, because the 50 lbs. act downward;

$10 \times F_1$ = positive moment, the reacting force $F_1$ acting upward.

As the beam is in equilibrium, these must be equal. That is, $10 \times F_1 = 4 \times 50$, making $F_1$ equal 20 lbs. This

* The length of a beam is considered as the distance between its supports.

equals the reaction at the left-end support, or the force necessary to support the left end of the beam.

To find the force necessary at the right-end support, take moments about the left end. Thus:

$$50 \times 6 = 10 \times F_2.$$

This gives $F_2 = 30$ lbs., which is the reacting force at the right end necessary to support the beam.

In all cases the sum of the vertical downward forces must equal the sum of the vertical upward forces, otherwise there would not be equilibrium. Hence, as a check on the above solution, $F_1 + F_2$ should equal the sum of the acting downward forces. That is, $30 + 20 = 50$.

The solution may also be proven by taking moments about any point in the beam between the supports, being careful to consider all forces and to note whether the moments are positive or negative.

From the above we may state the following general rule: *When a beam is in equilibrium, the sum of the downward forces must equal the sum of the upward forces, and the sum of the moments about any point within the beam must equal zero.*

### PROBLEMS

1. A machine weighing 550 lbs. is placed upon a 12-ft. beam 3 ft. from the right end. Find the reaction of the supports at each end of beam, due to this weight.

2. A steel shaft rests on two bearings 6 ft. apart and carries a pulley weighing 120 lbs. $3\frac{1}{2}$ ft. from one of the bearings. What is the pressure on each bearing caused by the pulley?

3. A wrought-iron girder 20 ft. long has a load of 1000 lbs. located 3 ft. from the right end, a 700 lb. machine 8 ft. from that, and a 1100-lb. machine 5 ft. from that. Find the reactions at the supports as a result of this loading.

4. A traveling crane weighing 2800 lbs. has a span of 25 ft. What is the pressure upon the supports at each end? The crane lifts a 900-lb. machine 10 ft. from the right end. Find the added pressure on each end support.

5. A piece of shafting 8 ft. long weighs 82 lbs. and has a 40-lb. pulley 6 ft. from one end. It is lifted by two men, one at each end. What is the weight carried by each?

6. Two men carry a 12-ft. channel beam weighing 10 lbs. per foot. One man is at each end. How much weight is carried by each man?

7. Two hangers 12 ft. apart carry shafting weighing 18 lbs. per foot. A 45-lb. pulley is 4 feet from the right end and a 25-lb. pulley 2 ft. from the other end. What weight is carried by each hanger?

8. A bar 10 ft. long is used by 2 men in carrying a load of 160 lbs. If the bar weighs 32 lbs. and the load is placed 4 ft. from one end, how much of the load is each man carrying?

9. A beam 18 ft. long carries a 600-lb. load due to a weight placed 10 ft. from the left-end support. What is the pressure on each support due to the load?

**71. Center of Acting Forces.** A series of parallel

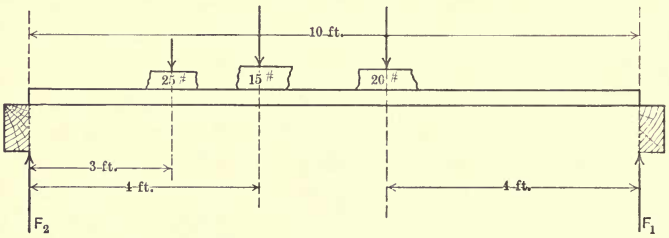



FIG. 68.

forces in the same direction may be represented by a single force. The moment of this force about any axis must be equal to the sum of the moments of all the other forces. *The position of the force from a given point is found by divid-*

*ing the sum of the moments taken about this point by the sum of the acting forces.*

This point at which the equivalent force acts is called the *center of action* of the forces. The effect produced by this one force at this point is the same as that of all the other forces acting in their respective positions.

As an illustration, assume that on the 10-ft. bar shown in Fig. 68, a force of 25 lbs. acts 3 ft. from the left end, one of 15 lbs. at 4 ft. from the left end, and one of 20 lbs. acts at 4 ft. from the right end. Where is the center of the acting forces and what is the value of the equivalent force acting at this point?

The weights act downward, therefore the supporting forces act upward. The reaction at the right-end support is found by taking moments about the left support, as explained in the first example on beams.

$$10F_1 = (3\times25)+(4\times15)+(6\times20)$$
$$= 225,$$

or,
$$F_1 = 25.5 \text{ lbs.}$$

The reaction at the left support is found by taking moments about the right support as above, placing the positive moments equal to the negative moments, for these must be equal if the beam is in equilibrium.

$$10F_2 = (20\times4)+(6\times15)+(7\times25)$$
$$= 345,$$

or,
$$F_2 = 34.5.$$

According to the rule, $F_1+F_2$ should equal the sum of the downward forces.

$34.5+25.5=60$ lbs. = sum of supporting forces;

$25+15+20=60$ lbs. = sum of acting downward forces.

NOTE. Check for $F_1$ and $F_2$ may be made by taking moments at other points and proceeding as above.

RULE. *To find the location of the center of action of a set of parallel forces, take moments of these forces about either support and divide their sum by the sum of the acting forces. The result is the distance the center of the acting forces lies from the point about which the moments were taken.*

Taking moments about the right end of the beam under consideration, we have:

$$20\times4=80$$
$$15\times6=90$$
$$25\times7=175$$

$345$ = sum of moments about right end.

The sum of the acting downward forces $=20+15+25=60$ lbs.

By dividing the sum of the moments by the sum of the forces, according to the above rule, we have $\frac{345}{60}=5.75$ ft. to left of right-end support, as the location of the center of action of the forces.

That is, a force of 60 lbs. placed $5\frac{3}{4}$ ft. from right end will produce the same downward pressure upon the supports as the three forces acting in their respective positions.

This last result may be proven as follows:

With 60 lbs. acting $5\frac{3}{4}$ ft. from the right end, take moments at each end to find if the supporting forces are the same as before.

$5\frac{3}{4} \times 60 = 10F_2$;

$345 = 10F_2$;

$F_2 = 34.5 =$ correct left-supporting force;

$10F = 60 \times 4\frac{1}{4}$;

$10F = 255$;

$F = 25.5 =$ correct right-supporting force.

This shows that the supporting forces are identical with those in the first case, which proves that a force of 60 lbs. $5\frac{3}{4}$ ft. from the left end produces the same effect as the several forces in their respective positions. Further, the sum of the moments about any point in the bar should equal zero so long as the bar is in equilibrium. This may be proven by selecting the point about which to take moments and adding the moments, being careful to have the signs correct.

## PROBLEMS ON THE CENTER OF ACTION OF PARALLEL FORCES

1. A 6-ft. rod has weights of 8 and 10 lbs. at each end and a 4-lb. weight in the middle. Find by calculation the point at which the rod will balance. Test a rod as above to find the balancing point.

2. A 16-ft. shaft supported at each end has 2 pulleys of 50 lbs. and 40 lbs. each, 4 ft. from either end, and a 130-lb. pulley 6 ft. from the right-end pulley. Neglecting the weight of the shaft, where is the point to place a hanger so that it is in the center of the acting weights?

3. A 20-ft. beam has two loads, one of 1200 lbs. 8 ft. from the right end, and the other of 1000 lbs. 6 ft. from the left end. Where would be the most advisable place to locate a supporting post, if the only supports were those upon which the ends of the beam rested?

**72. Center of Gravity of Solids.** The center of gravity of a body is that point within the body at which all of its weight seems to be concentrated.

The approximate center of gravity of disks and flat pieces may be found by suspending them by a piece of cord from three or four positions and tracing on the disk or flat piece a line representing the direction of the cord. The point of intersection of the several lines is the center of gravity of the surface.

This suspension of a weight by a cord illustrates also the fact that a body will not remain at rest unless the center of gravity of the weight lies within the line of support. This accounts for the swaying from side to side and the gradual settling in one spot. This can also be proven by taking moments. If the moments do not equal zero, the body will not be at rest.

The center of gravity of a regular body is readily found by inspection. In cubical and rectangular bodies, the center of gravity lies where the diagonals cross each other; in cylindrical bodies it is located on the axis midway between the ends; in spherical solids it is at the center; in triangles it lies one third of the way up on the line that runs from the center of the base to the top; in pyramids and cones it lies one quarter of the way up on the line running from the center of the base to the apex.

## CHAPTER VII

### STRESS AND STRAIN

**73. Stress.** If a force of 750 lbs. be exerted upon one end of a 2″ square bar in the direction of its length, and the bar remains at rest, there must be acting upon it in order to produce equilibrium an equal force in an opposite direction. This force exerts upon any section of the bar at right angles to it an internal force known as a stress.

Commonly speaking, a stress is an internal force acting over a unit of area, and is found by dividing the external force acting, by the area at right angles to it and over which it acts.

If in the case above, the acting force is a pull, the bar is in tension. The resulting stress is called a *tensile stress*, and is usually referred to as the tensile stress per square inch.

If the acting force is a push, the bar is in compression. This stress is a *compressive stress*, and is referred to as the compressive stress per square inch.

These are also conditions which effect the proper framing of roof trusses. Because of weights due to snow and wind loads, and the weight of a certain area of roof, together with any extra loads, the roof truss is so framed that its web members are placed in positions to withstand such loads to best advantage. As a result the forces act in the direction of the length of the members, producing either tension

or compression. To this kind of a stress the truss offers greatest resistance.

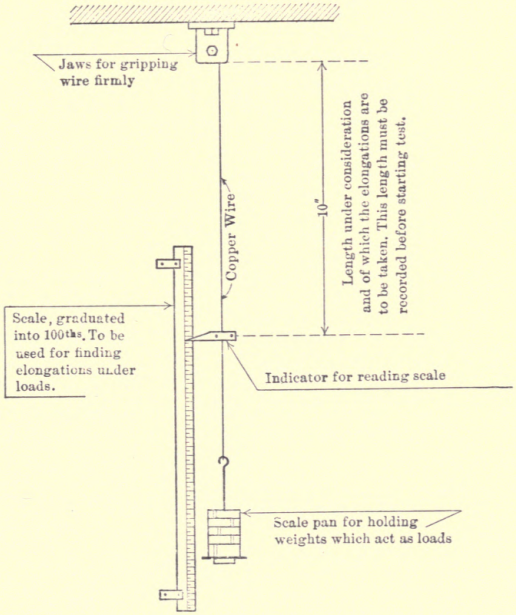
Tie rods, tie beams, chains and cables, and such, are usually in tension, while columns or struts are usually in compression.

**74. Strain.** Besides being subjected to a stress, the 2″ bar mentioned above undergoes a slight change in its length. The effect of such change may be more clearly seen by suspending a strip of rubber, and, after measuring off two points that are 10″ apart, attaching a weight at the lower end of the strip. It will be observed that there is a change in the distance between the points. This change in 10″ is called the elongation. The *change per unit of length*, or the change per inch in this case, is found by dividing the elongation by 10. This change of length per unit of length between the points where the measurements were taken is called the *strain.*

If the piece is in tension, the change will be an elongation and the strain is a *tensile strain.* If in compression the change is a reduction in length and the strain is a *compressive strain.*

**75. Elongation of a Copper Wire under Tension.** To understand more clearly what is taking place in a piece subjected to the action of external forces, arrange a simple tension machine as in Fig. 69 and fasten a piece of No. 18 copper wire to a hook, indicating carefully on the wire two points that are 10″ apart. After attaching weights to a scale-pan fastened on the lower end of the wire, keep note of the elongation and loads, and arrange them according to the following suggestions on a chart of plotting paper, as on the accompanying plot, Fig. 70, which shows the action of a piece of copper wire under similar conditions.

To arrange the points which represent the elongations and loads on the copper wire so as to determine the path of the curve which shows its action under these loads, use a plotting paper that is ruled up into tenths. Select in the lower left corner of the sheet, a point where a heavy


Jaws for gripping wire firmly
Copper Wire
10"
Length under consideration and of which the elongations are to be taken. This length must be recorded before starting test.
Scale, graduated into 100ths. To be used for finding elongations under loads.
Indicator for reading scale
Scale pan for holding weights which act as loads

F.G. 69.—Apparatus for Measuring the Elongation of a Wire.

blue horizontal line crosses a heavy blue vertical line, and label this point "0." Using two of the smallest horizontal divisions to represent an elongation of $\frac{1}{10}''$, space off to the right of the "0" mark the number of divisions which represent the amount of the first elongation. Using

two of the smallest vertical divisions to represent each pound of applied load, space off directly above the point which represents the first elongation, the amount of the

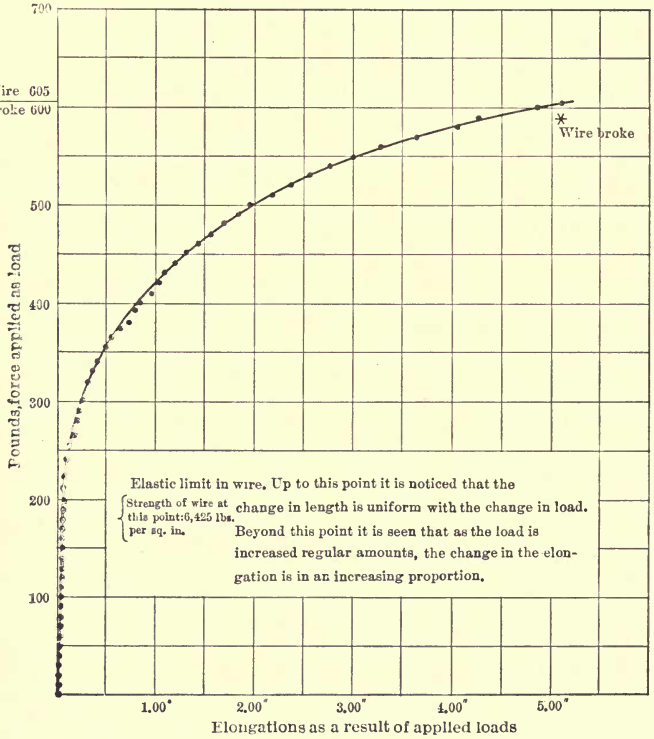

700
Wire 605
broke 600
500
400
300
200
100
Pounds, force applied as load
Wire broke
Elastic limit in wire. Up to this point it is noticed that the change in length is uniform with the change in load.
Strength of wire at this point: 6,425 lbs. per sq. in.
Beyond this point it is seen that as the load is increased regular amounts, the change in the elongation is in an increasing proportion.
1.00"
2.00"
3.00"
4.00"
5.00"
Elongations as a result of applied loads

FIG. 70.—Curve Showing Elongation of a Copper Wire.

load which gave this elongation. To locate the second point for the plot, space off on a horizontal line directly opposite the point which represents the second load, the number of divisions which represent the second elongation.

And so with each elongation, its proper position is determined by spacing off its amount directly opposite the division which represents the load for that amount.

It will be observed that as the load is increased there is a corresponding increase in the length of the wire, and that its length increases at a certain rate as the load increases. The result of this part of the plot is a straight line. This shows that as the stress increases there is a corresponding increase in the strain, and the stress continues to bear the same relation to the strain up to a certain point when it is noticed that as the load is applied, there is a marked increase in the length of the wire which continues to stretch more and more as the load is applied. The resulting curve at this point drops off and the stress and strain no longer continue the same relation as before, the strain becoming greater for slight increases in the load. This point is known as the *elastic limit.*

If the load were taken off at the elastic limit, or better, just before it was reached, the wire would tend to return to its original length. Beyond the elastic limit the piece will not retain its shape nor return to its original length, as it has become over-strained and a permanent set has taken place.

The stretch continues to increase very rapidly until a point is reached where the stretch takes place without applying any extra load. This is known as the *yield point,* and indicates that the piece is about to break.

By drawing a continuous line through the plotted points on the plotting paper, a resulting curve is given which shows the behavior of the wire under the acting loads.

**76. Modulus of Elasticity.** The relation of the stress to the strain up to the elastic limit is called the *modulus of elasticity,* and is found by dividing the stress by the

strain. This relation is a very important one in determining the strength of materials.

**77. Ultimate Strength.** The load per square inch at which the wire breaks is called the *ultimate strength* of the wire. The load per square inch is found by dividing the total load on the piece by the original area of the wire.

**78. Factor of Safety.** As a piece of metal could never be subjected to such a loading in practice, a certain fraction of the breaking load is used as the greatest allowable load. The ultimate strength divided by the actual stress gives the *factor of safety*. The value of this factor depends upon the material and the conditions governing the loading, also the use to which the piece is put after loading.

It is of great value in designing parts that are subjected to stress and strains to know the value of the factor of safety and how to use it. If the piece be subjected to much wear and tear as are some parts of machines, as in automatic machinery, the factor must be high. Such parts are usually in hard use and in some cases the stress and strain are considerable, and so the parts must be designed and built heavy enough to withstand the continual shocks. A high factor in such cases allows a fair loading and puts the member on the safe side.

Factors of safety must not be considered as absolute, as they are dependent upon the quality of the material and the use to which it is put. The following are results from common practice. Steel, cast iron, and wrought iron subjected to considerable usage, as in machinery, have a factor of 10 to 14. Much uncertainty is introduced here due to the fact that castings are brittle and cannot withstand shocks and jars to which they may be subjected.

The factors commonly recommended for mill work are 3 for a dead load, and 6 for a live load or a moving load.

If it is desired to find the *working strength* of a piece, divide the breaking strength by the factor of safety.

### PROBLEMS

1. If the tensile strength of cast iron is 12,000 lbs. per square inch and a factor of safety of 9 is used because of the usage to which the piece is put, what is the working strength in pounds per square inch?

2. A steel rod showing a shearing strength of 42,000 lbs. per square inch has a factor of safety of 12. As the rod fails first under shear, what is the allowable working load under such conditions?

3. In a line of shafting the lowest breaking strength is shown as 45,000 lbs. shear. If the factor used is 8, what would be the safe working strength?

4. A rod 1″ diameter breaks under a pull of 100,000 lbs. Compute the ultimate strength of the material. If a factor of safety of 4 is used, what is the safe working load in pounds per square inch?

**79. Repeated Stress.** Practice shows that a load which would not break a piece of material when first applied, would, after applied a great many times, completely rupture the piece. Parts that can stand a heavy load will break when repeatedly subjected to a lighter load. This is more noticeable, especially when the stress is changed repeatedly from compression to tension.

This continual complete change causes a fatigue in the material and it eventually gives way to the acting force. Results of such repeated stresses are noticed in bending a piece of tin or brass or such material, back and forth until it gives out. The same is true, but in a lesser degree, in locomotive axles, shafting (especially in shafting that is out of line), structural members, etc.

**80. Shearing Stress.** Shear is produced in a piece of metal or timber when it tends to break by the material on one side of a section sliding past that on the other

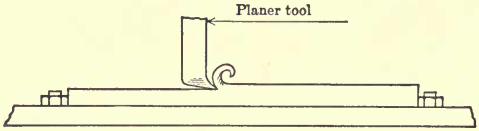



FIG. 71.—Shearing Action of a Planer Tool.

side, just as the blades of a pair of shears move with respect to each other.

Such action occurs during the cutting action in shear machines, punching machines, slotting machines, planers, lathes, etc.

The section along which the break occurs is subjected

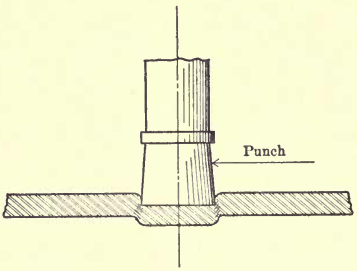


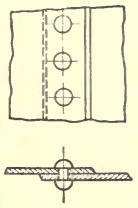

FIG. 72.—Shearing Action of a Punch.

to a *shearing stress*, the intensity of which is found, as in a direct stress, by dividing the force by the area over which it acts. If the shear is distributed over two sections, as in a pin in a knuckle joint, these two surfaces must be considered, and the intensity is found by dividing the acting

force by the sum of these two areas over which the force acts. In this case the pin is said to be in *double shear*.

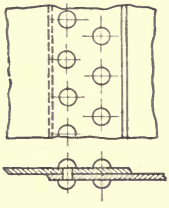
All forces that are not in the direct line of the axis of the member on which they are applied, produce a shearing effect upon the piece. This is true in nearly all structural work, beam bending, link motions, cutting tools, pulleys, keys in shafting, flywheels and revolving bodies, and pieces that are at any time subjected to a load which is off center or eccentric.

**81. Riveted Joints.** Rivets are used to fasten two or



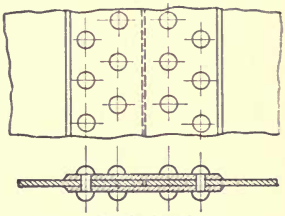
Single riveted lap joint

FIG. 73.



Double riveted lap joint

FIG. 74.



Double riveted butt joint with cover plate

FIG. 75.

more plates together. The pieces slightly overlap and are then riveted. When one row is used it is called a single-riveted joint (Fig. 73), where two are used it is a double-riveted joint (Fig. 74).

The holes should be centered exactly, and are either punched out or drilled. Punched holes are not so good as drilled ones as the shearing effect of the punch injures the edges of the hole and so weakens the joint. For this reason the better grade of riveted joints are those in which the rivet holes are drilled. Such drilling is best done by fastening the plates in position and drilling both together.

The shearing strength of plates, or the greatest shear

that a plate can resist, depends upon the material and its thickness. The force required to shear a punched hole in thin plate is found by multiplying the value of the shearing strength by the area under shear, the area under shear being equal to the circumference of the hole multiplied by the thickness of the metal.

### PROBLEMS ON STRENGTH OF MATERIALS

1. If the shearing strength of a mild steel key used in keying a pulley to a shaft is 42,000 lbs. per square inch, what would be the total force necessary to shear off a key $\frac{1}{4}''$ square and 6″ long?

2. A steel pin used in a toggle joint is in double shear. The shearing strength shows 45,000 lbs. per square inch. If a factor of 9 is used, what may be the greatest working pressure bearing upon the joint if the pin measures $\frac{7}{8}$ sq.in. in cross-section?

3. A plate riveted between two angle irons by 8 half-inch rivets is subjected to a total pull of 6000 lbs. Are the rivets in single or double shear? What is the shearing stress per square inch on each rivet?

4. What force will be required to punch a $\frac{3}{4}''$ hole through a $\frac{3}{16}''$ plate if 12 tons is its shearing strength per square inch?

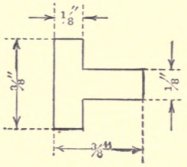
5. In a piece of steel $\frac{1}{4}''$ thick, what will be the force required to punch out a $\frac{5}{8}''$ hole when steel offers a resistance of 50,000 lbs. per square inch? What is the corresponding pressure upon the punch?

6. In punching out wrought-iron washers $\frac{1}{8}''$ thick, $1\frac{1}{4}''$ in diameter, what is the required force if the resistance to shear offered by the wrought iron is 20,000? If a $\frac{1}{2}''$ hole is punched through center, what will be the force required for that? What is the corresponding compression stress upon the punch?

7. A gate shears is operated to cut a steel bar $1\frac{1}{4}''$ square. The resistance to shear is 55.000 lbs. per square inch. What is the force required? If the blade moves through the bar four-fifths of the thickness before the bar breaks, how many horsepower are necessary to operate the machine if 12 cutting strokes per minute is its greatest capacity?

8. A punch drives holes through a wrought iron disc .250″

in thickness. The force needed to shear the hole is 20,000 lbs. How much work is being done in the operation? If 20 holes are punched per minute, what is the required horse-power?




9. A machine punching T-slots in high-grade steel plate $\frac{1}{4}''$ thick makes 10 cutting strokes per minute. The shearing resistance offered by the metal is 65,000 lbs. per square inch. Find the force necessary for one operation. What is the horse-power required?

# CHAPTER VIII

## ANGLE MEASUREMENTS

In working out problems that bring into use triangular measurements the following facts and definitions will be found most helpful.

**82. Sum of the Angles of a Triangle.** It should be remembered that the sum of the angles of a triangle always equals 180°. When any two angles are known, the third angle of the triangle may be found by subtracting from 180° the sum of the other two angles.

For example, if the two known angles of a triangle are 42° and 70°, then the other is the difference between 180° and (42°+70°) or 68°.

In a right-angle triangle there is always one right angle or 90° angle. So when one angle of a right triangle is known, the other is found by subtracting from 90° the number of degrees in the known angle.

**83. Relations between the Sides of a Right Triangle.** The sides of a right-angle triangle may be referred to in connection with a certain angle as:

1. The *side opposite*, meaning that side opposite the angle.
2. The *side adjacent*, meaning that side which is perpendicular to the side opposite and forming one side of the angle.
3. The *hypotenuse*, referring to the longest side of the triangle.

For any given right triangle the lengths of these sides bear fixed relationships to each other. And for all similar right-angle triangles, that is, triangles having the same angles in the same relative positions, the relations of these sides to each other are the same. The more common of these relationships of sides, or as they are more usually called, *functions* of angles, are as follows:

(*a*) **Sine** (written Sin). The sine of an angle is the relation of the side opposite that angle to the hypotenuse.

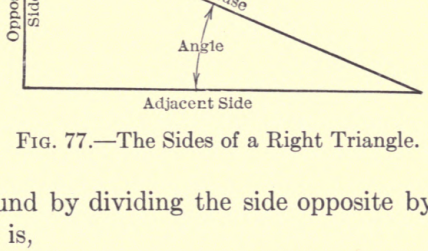



FIG. 77.—The Sides of a Right Triangle.

It is found by dividing the side opposite by the hypotenuse, that is,

$$\text{sine of an angle} = \frac{\text{side opposite}}{\text{hypotenuse}}.$$

The angle whose sine is equal to this value may be found by referring to a table of sines.

EXAMPLE. In a right triangle the sine of an angle equals .7660; it is desired to find the number of degrees in the angles. By referring to the table of sines it is seen that the angle whose sine is .7660 is 50°. The other angle would be the difference between this and 90° or 40°.

In a 30° angle the sine equals .5000; in a 45° angle the sine equals .7071; in a 60° angle the sine equals .8660.

This relation may be used also to find either the hypotenuse or the opposite side when either one and the angle are given.

To find the *hypotenuse* of a right-angle triangle, divide the side opposite by the sine of the angle.

$$\text{Hypotenuse} = \frac{\text{side opposite}}{\text{sine of angle}}.$$

EXAMPLE. A right angle "V" is planed in a casting such that the sloping sides of the cut each measure $1\frac{1}{4}''$. What is the distance across the top of this cut?

*Solution.* Distance across top of cut =

$$\text{hypotenuse} = \frac{1\frac{1}{4}}{\text{sine } 45°} = \frac{1.25}{.707} = 1.768''.$$

### PROBLEMS

1. The angle between the vertical and the slope of a roof is 60°. If the vertical height is 11 ft., what is the length of the slope?

2. The guy ropes of a flag pole make an angle of 30° with the pole. If they extend 15 ft. out from the base of the pole, how long are they?

The *opposite side* is found by multiplying the hypotenuse by the sine of the angle.

Opposite side = hypotenuse × sine of angle.

EXAMPLE. In a 45° right angle triangle, find the length of the vertical if the hypotenuse measures $1\frac{1}{2}''$.

*Solution.* $1.5'' \times .7071 = 1.061''$ length of vertical.

### PROBLEMS

1. In a certain drill jig two holes lie on a horizontal line $4\frac{1}{4}''$ apart, another hole is to be drilled above the left one of these, such that the line connecting it to the right hole makes 30° with the line connecting the first two holes. The line connecting it

with the left hole makes 60° with the line referred to as connecting the first two holes. What is its distance from the left hole, also from the right hole?

2. In laying out a piece of work for drilling the sketch shown in Fig. 78 is given the machinist. How far apart should he locate the holes?

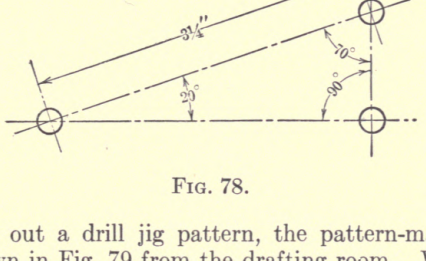



FIG. 78.

3. To lay out a drill jig pattern, the pattern-maker obtains the plan shown in Fig. 79 from the drafting room. What dimensions other than these should be given?

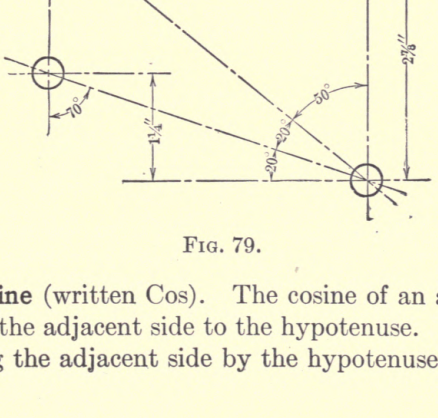



FIG. 79.

(*b*) **Cosine** (written Cos). The cosine of an angle is the relation of the adjacent side to the hypotenuse. It is found by dividing the adjacent side by the hypotenuse.

$$\text{Cos} = \frac{\text{adjacent side}}{\text{hypotenuse}}.$$

With this value given the angle may be found from the table of cosines, as in the case of the sine.

In a 30° angle the cosine equals .8660; in a 45° angle the cosine equals .7071; in a 60° angle the cosine equals .5000.

This relation is used in finding either the hypotenuse

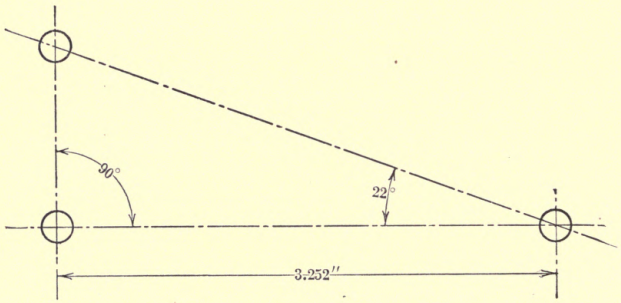



FIG. 80.

or the adjacent side when either one and the angle are given.

To find the hypotenuse of a right-angle triangle divide the adjacent side by the cosine of the angle.

$$\text{Hypotenuse} = \frac{\text{adjacent side}}{\text{cosine of angle}}.$$

EXAMPLE. Find the length of a roof rafter which makes an angle of 45° with the horizontal and extends 12 ft. out from the center line of the roof.

*Solution.* 12 ft. = adjacent side;

.7071 = cos 45°;

12 ÷ .7071 = 16.97 ft. or 16 ft. $11\frac{5}{8}''$ = length of rafter.

### PROBLEMS

1. What is the length of a guy rope for a flag pole if it is fastened 12 ft. out from base and extends up the pole at angle of 60° with the ground?

2. In boring out a piece on the milling machine according to the layout shown in Fig. 80, how far apart are the holes?

(*c*) **Tangent** (written Tan). The tangent of an angle is the relation of the side opposite to the side adjacent. Knowing this value, the angle may be found from the table of tangents. The value of the tangent is found by dividing the opposite side by the adjacent side.

$$\text{Tan} = \frac{\text{opposite side}}{\text{adjacent side}}.$$

In a 30° angle the tangent equals .5774; in a 45° angle the tangent equals 1.000; in a 60° angle the tangent equals 1.7320.

This relation is used to find either the opposite side or the adjacent side when either side and the angle are given.

To find the *adjacent side* divide the side opposite by the tangent of the angle.

$$\text{Side adjacent} = \frac{\text{side opposite}}{\text{tan of angle}}.$$

EXAMPLE. Calculate the depth of a " V " thread in terms of the pitch.

*Solution.* The angle of the " V " being 60°, the line drawn from the bottom of the " V " perpendicular to the line connecting the tops of the " V " would form two right triangles, each having the bottom angle equal to 30°.

One-half the distance across the " V " being the opposite side is equal to $\frac{1}{2}$ of pitch.

Then $$\frac{\frac{1}{2}\text{ of pitch}}{\text{tan of angle}} = \text{depth of " V "};$$

$$\text{Tan of angle} = \tan 30° = .5774.$$

Then $$\frac{P \div 2}{.5774} = \frac{P}{2 \times .5774} = \frac{P}{1.1548} = \text{depth of " V " in terms of pitch.}$$

## PROBLEMS

1. Calculate the depth of the cut in a " V " thread when there are 6 threads per inch.

2. In the U. S. Standard thread, the top and bottom of the " V " cut are flat, and the depth is only $\frac{3}{4}$ that of a " V " thread of same pitch. Calculate the depth in terms of the pitch.

3. An iron truss is built such that the sloping members make an angle of 25° with the horizontal and extend 12 ft. out from the center. How high is the truss?

To find the *opposite side* multiply the side adjacent by the tangent of the angle.

Opposite side = tan of angle × adjacent side.

EXAMPLE. A ladder making an angle of 60° with the ground leans against a vertical wall. If the base is 8 ft. out from foot of wall, how far up the wall does it extend?

*Solution.* The distance up the wall equals the opposite side of the 60° angle. The adjacent side equals 8 ft.

Tan 60° equals 1.732.

Then $1.732 \times 8 = 13.856$ ft. = distance ladder extends up the wall.

## PROBLEMS

1. Three holes are to be drilled in a jig such that they form a right triangle having 15° and 75° angle. The side adjacent to the 15° line measures $2\frac{1}{4}''$. Locate the other holes.

2. Determine the required dimensions on the layout of Fig. 81.

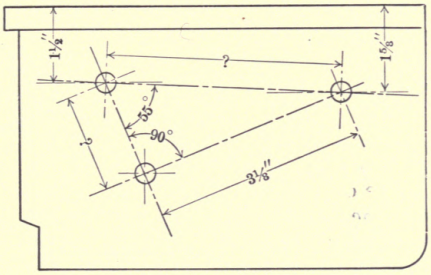



FIG. 81.

# APPENDIX

## Table 1

### AREAS OF CIRCLES

| Diam. | Circumf. | Area. | Diam. | Circumf. | Area. |
|---|---|---|---|---|---|
| $\frac{1}{4}$ | .7854 | .04909 | 23 | 72.256 | 415.476 |
| $\frac{1}{2}$ | 1.5708 | .1963 | 24 | 75.398 | 452.390 |
| $\frac{3}{4}$ | 2.3562 | .4417 | 25 | 78.540 | 490.875 |
| 1 | 3.1416 | .7854 | 26 | 81.681 | 530.93 |
| $1\frac{1}{2}$ | 4.7124 | 1.7671 | 27 | 84.823 | 572.56 |
| 2 | 6.2832 | 3.1416 | 28 | 87.964 | 615.75 |
| $2\frac{1}{2}$ | 7.8540 | 4.9087 | 29 | 91.106 | 660.52 |
| 3 | 9.4248 | 7.0686 | 30 | 94.247 | 706.86 |
| $3\frac{1}{2}$ | 10.995 | 9.6211 | 31 | 97.389 | 754.77 |
| 4 | 12.566 | 12.566 | 32 | 100.531 | 804.25 |
| 5 | 15.708 | 19.635 | 33 | 103.607 | 855.30 |
| 6 | 18.849 | 28.274 | 34 | 106.814 | 907.92 |
| 7 | 21.991 | 38.484 | 35 | 109.956 | 962.11 |
| 8 | 25.132 | 50.265 | 36 | 113.097 | 1017.9 |
| 9 | 28.274 | 63.617 | 37 | 116.239 | 1075.2 |
| 10 | 31.416 | 78.540 | 38 | 119.381 | 1134.1 |
| 11 | 34.558 | 95.033 | 39 | 122.522 | 1194.6 |
| 12 | 37.699 | 113.097 | 40 | 125.664 | 1256.6 |
| 13 | 40.840 | 132.732 | 41 | 128.805 | 1320.3 |
| 14 | 43.982 | 153.938 | 42 | 131.947 | 1385.4 |
| 15 | 47.124 | 176.715 | 43 | 135.088 | 1452.2 |
| 16 | 50.265 | 201.062 | 44 | 138.230 | 1520.5 |
| 17 | 53.407 | 226.980 | 45 | 141.372 | 1590.4 |
| 18 | 56.548 | 254.469 | 46 | 144.513 | 1661.9 |
| 19 | 59.690 | 283.529 | 47 | 147.655 | 1734.9 |
| 20 | 62.832 | 314.160 | 48 | 150.796 | 1809.6 |
| 21 | 65.973 | 346.361 | 49 | 153.938 | 1885.7 |
| 22 | 69.115 | 380.133 | 50 | 157.080 | 1963.5 |

## TABLE 2

### SQUARES, SQUARE ROOTS, CUBES AND CUBE ROOTS

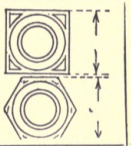
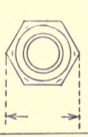
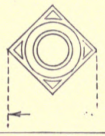
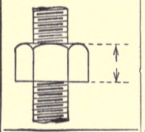
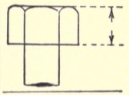
| No. | Square. | Square Root. | Cube. | Cubic Root. |
|---|---|---|---|---|
| 2 | 4 | 1.414 | 8 | 1.25 |
| 3 | 9 | 1.732 | 27 | 1.44 |
| 4 | 16 | 2.000 | 64 | 1.58 |
| 5 | 25 | 2.236 | 125 | 1.71 |
| 6 | 36 | 2.449 | 216 | 1.81 |
| 7 | 49 | 2.645 | 343 | 1.91 |
| 8 | 64 | 2.828 | 512 | 2.00 |
| 9 | 81 | 3.000 | 729 | 2.08 |
| 10 | 100 | 3.162 | 1,000 | 2.15 |
| 11 | 121 | 3.316 | 1,331 | 2.22 |
| 12 | 144 | 3.464 | 1,728 | 2.28 |
| 13 | 169 | 3.605 | 2,197 | 2.351 |
| 14 | 196 | 3.741 | 2,744 | 2.410 |
| 15 | 225 | 3.873 | 3,375 | 2.466 |
| 16 | 256 | 4.000 | 4,096 | 2.519 |
| 17 | 289 | 4.123 | 4,913 | 2.571 |
| 18 | 324 | 4.242 | 5,832 | 2.620 |
| 19 | 361 | 4.358 | 6,859 | 2.668 |
| 20 | 400 | 4.472 | 8,000 | 2.714 |
| 21 | 441 | 4.582 | 9,261 | 2.758 |
| 22 | 484 | 4.690 | 10,648 | 2.802 |
| 23 | 529 | 4.795 | 12,167 | 2.843 |
| 24 | 576 | 4.898 | 13,824 | 2.884 |
| 25 | 625 | 5.000 | 15,625 | 2.924 |
| 26 | 676 | 5.099 | 17,576 | 2.962 |
| 27 | 729 | 5.196 | 19,683 | 3.000 |
| 28 | 784 | 5.291 | 21,952 | 3.036 |
| 29 | 841 | 5.385 | 24,389 | 3.072 |
| 30 | 900 | 5.477 | 27,000 | 3.107 |
| 31 | 961 | 5.567 | 29,791 | 3.141 |
| 32 | 1024 | 5.656 | 32,768 | 3.174 |
| 33 | 1089 | 5.744 | 35,937 | 3.207 |
| 34 | 1156 | 5.830 | 39,304 | 3.239 |
| 35 | 1225 | 5.916 | 42,875 | 3.271 |
| 36 | 1296 | 6.000 | 46,656 | 3.301 |
| 37 | 1369 | 6.082 | 50,653 | 3.332 |
| 38 | 1444 | 6.164 | 54,872 | 3.361 |
| 39 | 1521 | 6.244 | 59,319 | 3.391 |
| 40 | 1600 | 6.324 | 64,000 | 3.420 |

TABLE 2—*Continued*

| No. | Square. | Square Root. | Cube. | Cubic Root. |
|---|---|---|---|---|
| 41 | 1681 | 6.403 | 68,921 | 3.448 |
| 42 | 1764 | 6.480 | 74,088 | 3.476 |
| 43 | 1849 | 6.557 | 79,507 | 3.503 |
| 44 | 1936 | 6.633 | 85,184 | 3.530 |
| 45 | 2025 | 6.708 | 91,125 | 3.556 |
| 46 | 2116 | 6.782 | 97,336 | 3.583 |
| 47 | 2209 | 6.855 | 103,823 | 3.608 |
| 48 | 2304 | 6.928 | 110,591 | 3.634 |
| 49 | 2401 | 7.000 | 117,649 | 3.659 |
| 50 | 2500 | 7.071 | 125,000 | 3.684 |

## TABLE 3

### NUTS, SCREWS AND TAP DRILL SIZES

| Diam. | Threads per In. | Diam. at Root. | Diam. Tap Drill. |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|
| 1/4 | 20 | 0.185 | 13/64 | 1/2 | 0.578 | 0.707 | 1/4 | 1/4 |
| 5/16 | 18 | 0.240 | 1/4 | 19/32 | 0.686 | 0.840 | 5/16 | 19/64 |
| 3/8 | 16 | 0.294 | 5/16 | 11/16 | 0.794 | 0.972 | 3/8 | 13/32 |
| 7/16 | 14 | 0.345 | 23/64 | 25/32 | 0.902 | 1.105 | 7/16 | 25/64 |
| 1/2 | 13 | 0.400 | 27/64 | 7/8 | 1.011 | 1.237 | 1/2 | 7/16 |
| 9/16 | 12 | 0.454 | 15/32 | 31/32 | 1.119 | 1.370 | 9/16 | 31/64 |
| 5/8 | 11 | 0.507 | 17/32 | 1 1/16 | 1.227 | 1.502 | 5/8 | 17/32 |
| 3/4 | 10 | 0.620 | 41/64 | 1 1/4 | 1.444 | 1.768 | 3/4 | 5/8 |
| 7/8 | 9 | 0.731 | 3/4 | 1 7/16 | 1.660 | 2.033 | 7/8 | 23/32 |
| 1 | 8 | 0.838 | 55/64 | 1 5/8 | 1.877 | 2.298 | 1 | 13/16 |
| 1 1/8 | 7 | 0.939 | 31/32 | 1 13/16 | 2.093 | 2.563 | 1 1/8 | 29/32 |
| 1 1/4 | 7 | 1.064 | 1 3/32 | 2 | 2.310 | 2.828 | 1 1/4 | 1 |
| 1 3/8 | 6 | 1.158 | 1 7/32 | 2 3/16 | 2.527 | 3.093 | 1 3/8 | 1 3/32 |
| 1 1/2 | 6 | 1.283 | 1 11/32 | 2 3/8 | 2.743 | 3.358 | 1 1/2 | 1 3/16 |
| 1 5/8 | 5 1/2 | 1.389 | 1 27/64 | 2 9/16 | 2.960 | 3.623 | 1 5/8 | 1 9/32 |
| 1 3/4 | 5 | 1.490 | 1 17/32 | 2 3/4 | 3.176 | 3.889 | 1 3/4 | 1 3/8 |
| 1 7/8 | 5 | 1.615 | 1 21/32 | 2 15/16 | 3.393 | 4.154 | 1 7/8 | 1 15/32 |
| 2 | 4 1/2 | 1.711 | 1 49/64 | 3 1/8 | 3.609 | 4.419 | 2 | 1 9/16 |
| 2 1/4 | 4 1/2 | 1.961 | 2 1/64 | 3 1/2 | 4.043 | 4.949 | 2 1/4 | 1 3/4 |
| 2 1/2 | 4 | 2.175 | 2 15/64 | 3 7/8 | 4.476 | 5.479 | 2 1/2 | 1 15/16 |
| 2 3/4 | 4 | 2.425 | 2 31/64 | 4 1/4 | 4.909 | 6.010 | 2 3/4 | 2 1/8 |
| 3 | 3 1/2 | 2.629 | 2 11/16 | 4 5/8 | 5.342 | 6.540 | 3 | 2 5/16 |

## TABLE 4

## NATURAL SINES, COSINES, TANGENTS AND COTANGENTS

**0° to 6°** | **7° to 13°**

| | sin | cos | tan | cot | | | sin | cos | tan | cot | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **0°** | .000000 | 1.00000 | .00000 | ∞ | **90°** | **7°** | .12187 | .99255 | .12278 | 8.1443 | **83°** |
| 10′ | 2909 | 000 | 291 | 343.77 | 50′ | 10′ | 476 | 219 | 574 | 7.9530 | 50′ |
| 20′ | 5818 | 998 | 582 | 171.89 | 40′ | 20′ | 764 | 182 | 869 | .7704 | 40′ |
| 30′ | 8727 | 996 | 873 | 114.59 | 30′ | 30′ | .13053 | 144 | .13165 | .5958 | 30′ |
| 40′ | 1635 | 993 | 164 | 85.940 | 20′ | 40′ | 341 | 106 | 461 | .4287 | 20′ |
| 50′ | 4544 | 989 | 455 | 68.750 | 10′ | 50′ | 629 | 067 | 758 | .2687 | 10′ |
| **1°** | .017452 | .99985 | .01746 | 57.290 | **89°** | **8°** | .13917 | .99027 | .14054 | 7.1154 | **82°** |
| 10′ | .02036 | 979 | .02036 | 49.104 | 50′ | 10′ | .14205 | .98986 | 351 | 6.9682 | 50′ |
| 20′ | 327 | 973 | 328 | 42.964 | 40′ | 20′ | 493 | 944 | 648 | .8269 | 40′ |
| 30′ | 618 | 966 | 619 | 38.188 | 30′ | 30′ | 781 | 902 | 945 | .6912 | 30′ |
| 40′ | 908 | 958 | 910 | 34.368 | 20′ | 40′ | .15069 | 858 | .15243 | .5606 | 20′ |
| 50′ | 199 | 949 | 201 | 31.242 | 10′ | 50′ | 356 | 814 | 540 | .4348 | 10′ |
| **2°** | .03490 | .99930 | .03492 | 28.636 | **88°** | **9°** | .15643 | .98769 | .15838 | 6.3138 | **81°** |
| 10′ | 781 | 929 | 783 | 26.432 | 50′ | 10′ | 931 | 723 | .16137 | .1970 | 50′ |
| 20′ | .04071 | 917 | .04075 | 24.542 | 40′ | 20′ | .16218 | 676 | 435 | .0844 | 40′ |
| 30′ | 362 | 905 | 366 | 22.904 | 30′ | 30′ | 505 | 629 | 734 | 5.9758 | 30′ |
| 40′ | 653 | 892 | 658 | 21.470 | 20′ | 40′ | 792 | 580 | .17033 | .8708 | 20′ |
| 50′ | 943 | 878 | 949 | 20.206 | 10′ | 50′ | .17078 | 531 | 333 | .7694 | 10′ |
| **3°** | .05234 | .99863 | .05241 | 19.081 | **87°** | **10°** | .17365 | .98481 | .17633 | 5.6713 | **80°** |
| 10′ | 524 | 847 | 533 | 18.075 | 50′ | 10′ | 651 | 430 | 933 | .5764 | 50′ |
| 20′ | 814 | 831 | 824 | 17.169 | 40′ | 20′ | 937 | 378 | .18233 | .4845 | 40′ |
| 30′ | .06105 | 813 | .06116 | 16.350 | 30′ | 30′ | .18224 | 325 | 534 | .3955 | 30′ |
| 40′ | 395 | 795 | 408 | 15.605 | 20′ | 40′ | 509 | 272 | 835 | .3093 | 20′ |
| 50′ | 685 | 776 | 700 | 14.924 | 10′ | 50′ | 795 | 218 | .19136 | .2257 | 10′ |
| **4°** | .06976 | .99756 | .06993 | 14.301 | **86°** | **11°** | .19081 | .98163 | .19438 | 5.1446 | **79°** |
| 10′ | .07266 | 736 | .07285 | 13.727 | 50′ | 10′ | 366 | 107 | 740 | .0658 | 50′ |
| 20′ | 556 | 714 | 578 | .197 | 40′ | 20′ | 652 | 050 | .20042 | 4.9894 | 40′ |
| 30′ | 846 | 692 | 870 | 12.706 | 30′ | 30′ | 937 | .97992 | 345 | .9152 | 30′ |
| 40′ | .08136 | 668 | .08163 | .251 | 20′ | 40′ | .20222 | 934 | 648 | .8430 | 20′ |
| 50′ | 426 | 644 | 456 | 11.826 | 10′ | 50′ | 507 | 875 | 952 | .7729 | 10′ |
| **5°** | .08716 | .99619 | .08749 | 11.430 | **85°** | **12°** | .20791 | .97815 | .21256 | 4.7046 | **78°** |
| 10′ | .09005 | 594 | .09042 | .059 | 50′ | 10′ | .21076 | 754 | 560 | .6382 | 50′ |
| 20′ | 295 | 567 | 335 | 10.712 | 40′ | 20′ | 360 | 692 | 864 | .5736 | 40′ |
| 30′ | 585 | 540 | 629 | .385 | 30′ | 30′ | 644 | 630 | .22169 | .5107 | 30′ |
| 40′ | 874 | 511 | 923 | .078 | 20′ | 40′ | 928 | 566 | 475 | .4494 | 20′ |
| 50′ | .10164 | 482 | .10216 | 9.7882 | 10′ | 50′ | .22212 | 502 | 781 | .3897 | 10′ |
| **6°** | .10453 | .99452 | .10510 | 9.5144 | **84°** | **13°** | .22495 | .97437 | .23087 | 4.3315 | **77°** |
| 10′ | 742 | 421 | 805 | .2553 | 50′ | 10′ | 778 | 371 | 393 | .2747 | 50′ |
| 20′ | .11031 | 390 | .11099 | .0098 | 40′ | 20′ | .23062 | 304 | 700 | .2193 | 40′ |
| 30′ | 320 | 357 | 394 | 8.7769 | 30′ | 30′ | 345 | 237 | .24008 | .1653 | 30′ |
| 40′ | 609 | 324 | 688 | .5555 | 20′ | 40′ | 627 | 169 | 316 | .1126 | 20′ |
| 50′ | 898 | 290 | 983 | .3450 | 10′ | 50′ | 910 | 100 | 624 | .0611 | 10′ |
| | cos | sin | cot | tan | | | cos | sin | cot | tan | |

**84° to 90°** | **77° to 83°**

| | 14° to 21° | | | | | | 22° to 29° | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | sin | cos | tan | cot | | | sin | cos | tan | cot | |
| **14°** | .24192 | .97030 | .24933 | 4.0108 | **76°** | **22°** | .37461 | .92718 | .40403 | 2.4751 | **68°** |
| 10′ | 474 | .96959 | .25242 | 3.9617 | 50′ | 10′ | 730 | 609 | 741 | .4545 | 50′ |
| 20′ | 756 | 887 | 552 | .9136 | 40′ | 20′ | 999 | 499 | .41081 | .4342 | 40′ |
| 30′ | .25038 | 815 | 862 | .8667 | 30′ | 30′ | .38268 | 388 | 421 | .4142 | 30′ |
| 40′ | 320 | 742 | .26172 | .8208 | 20′ | 40′ | 537 | 276 | 763 | .3945 | 20′ |
| 50′ | 601 | 667 | 483 | .7760 | 10′ | 50′ | 805 | 164 | .42105 | .3750 | 10′ |
| **15°** | .25882 | .96593 | .26795 | 3.7321 | **75°** | **23°** | .39073 | .92050 | .42447 | 2.3559 | **67°** |
| 10′ | .26163 | 517 | .27107 | .6891 | 50′ | 10′ | 341 | .91936 | 791 | .3369 | 50′ |
| 20′ | 443 | 440 | 419 | .6470 | 40′ | 20′ | 608 | 822 | .43136 | .3183 | 40′ |
| 30′ | 724 | 363 | 732 | .6059 | 30′ | 30′ | 875 | 706 | 481 | .2998 | 30′ |
| 40′ | .27004 | 285 | .28046 | .5656 | 20′ | 40′ | .40141 | 590 | 828 | .2817 | 20′ |
| 50′ | 284 | 206 | 360 | .5261 | 10′ | 50′ | 408 | 472 | .44175 | .2637 | 10′ |
| **16°** | .27564 | .96126 | .28675 | 3.4874 | **74°** | **24°** | .40674 | .91355 | .44523 | 2.2460 | **66°** |
| 10′ | 845 | 046 | 990 | .4475 | 50′ | 10′ | 939 | 236 | 872 | .2286 | 50′ |
| 20′ | .28123 | .95964 | .29305 | .4124 | 40′ | 20′ | .41204 | 116 | .45222 | .2113 | 40′ |
| 30′ | 402 | 882 | 621 | .3759 | 30′ | 30′ | 469 | .90996 | 573 | .1943 | 30′ |
| 40′ | 680 | 799 | 938 | .3402 | 20′ | 40′ | 734 | 875 | 924 | .1775 | 20′ |
| 50′ | 959 | 715 | .30255 | .3052 | 10′ | 50′ | 998 | 753 | .46277 | .1609 | 10′ |
| **17°** | .29237 | .95630 | .30573 | 3.2709 | **73°** | **25°** | .42262 | .90631 | .46631 | 2.1445 | **65°** |
| 10′ | 515 | 545 | 891 | .2371 | 50′ | 10′ | 525 | 507 | 985 | .1283 | 50′ |
| 20′ | 793 | 459 | .31210 | .2041 | 40′ | 20′ | 788 | 383 | .47341 | .1123 | 40′ |
| 30′ | .30071 | 372 | 530 | .1716 | 30′ | 30′ | .43051 | 259 | 698 | .0965 | 30′ |
| 40′ | 348 | 284 | 850 | .1397 | 20′ | 40′ | 313 | 133 | .48055 | 809 | 20′ |
| 50′ | 625 | 195 | .32171 | .1084 | 10′ | 50′ | 575 | 007 | 414 | 655 | 10′ |
| **18°** | .30902 | .95106 | .32492 | 3.0777 | **72°** | **26°** | .43837 | .89879 | .48773 | 2.0503 | **64°** |
| 10′ | .31178 | 015 | 814 | .0475 | 50′ | 10′ | .44098 | 752 | .49134 | 353 | 50′ |
| 20′ | 454 | .94924 | .33136 | .0178 | 40′ | 20′ | 359 | 623 | 495 | 204 | 40′ |
| 30′ | 730 | 832 | 460 | 2.9887 | 30′ | 30′ | 620 | 493 | 858 | 057 | 30′ |
| 40′ | .32006 | 740 | 783 | .9600 | 20′ | 40′ | 880 | 363 | .50222 | 1.9912 | 20′ |
| 50′ | 282 | 646 | .34108 | .9319 | 10′ | 50′ | .45140 | 232 | 587 | 768 | 10′ |
| **19°** | .32557 | .94552 | .34433 | 2.9042 | **71°** | **27°** | .45399 | .89101 | .50953 | 1.9626 | **63°** |
| 10′ | 832 | 457 | 758 | .8770 | 50′ | 10′ | 658 | .88968 | .51319 | 486 | 50′ |
| 20′ | .33106 | 361 | .35085 | .8502 | 40′ | 20′ | 917 | 835 | 688 | 347 | 40′ |
| 30′ | 381 | 264 | 412 | .8239 | 30′ | 30′ | .46175 | 701 | .52057 | 210 | 30′ |
| 40′ | 655 | 167 | 740 | .7980 | 20′ | 40′ | 433 | 566 | 427 | 074 | 20′ |
| 50′ | 929 | 068 | .36068 | .7725 | 10′ | 50′ | 690 | 431 | 798 | .8940 | 10′ |
| **20°** | .34202 | .93969 | .36397 | 2.7475 | **70°** | **28°** | .46947 | .88295 | .53171 | 1.8807 | **62°** |
| 10′ | 475 | 869 | 727 | .7228 | 50′ | 10′ | .47204 | 158 | 545 | 676 | 50′ |
| 20′ | 748 | 769 | .37057 | .6985 | 40′ | 20′ | 460 | 020 | 920 | 546 | 40′ |
| 30′ | .35021 | 667 | 388 | .6746 | 30′ | 30′ | 716 | .87882 | .54296 | 418 | 30′ |
| 40′ | 293 | 565 | 720 | .6511 | 20′ | 40′ | 971 | 743 | 673 | 291 | 20′ |
| 50′ | 565 | 462 | .38053 | .6279 | 10′ | 50′ | .48226 | 603 | .55051 | 165 | 10′ |
| **21°** | .35837 | .93358 | .38386 | 2.6051 | **69°** | **29°** | .48481 | .87462 | .55431 | 1.8040 | **61°** |
| 10′ | .36108 | 253 | 721 | .5826 | 50′ | 10′ | 735 | 321 | 812 | .7917 | 50′ |
| 20′ | 379 | 148 | .39055 | .5605 | 40′ | 20′ | 989 | 178 | .56194 | 796 | 40′ |
| 30′ | 650 | 042 | 391 | .5386 | 30′ | 30′ | .49242 | 036 | 577 | 675 | 30′ |
| 40′ | 921 | .92935 | 727 | .5172 | 20′ | 40′ | 495 | .86892 | 962 | 556 | 20′ |
| 50′ | .37191 | 827 | .40065 | .4960 | 10′ | 50′ | 748 | 748 | .57348 | 437 | 10′ |
| | cos | sin | cot | tan | | | cos | sin | cot | tan | |
| | 69° to 76° | | | | | | 61° to 68° | | | | |

## 30° to 37°

| | sin | cos | tan | cot | |
|---|---|---|---|---|---|
| **30°** | .50000 | .86603 | .57735 | 1.7321 | **60°** |
| 10′ | 252 | 457 | .58124 | 205 | 50′ |
| 20′ | 503 | 310 | 513 | 090 | 40′ |
| 30′ | 754 | 163 | 905 | .6977 | 30′ |
| 40′ | .51004 | 015 | .59297 | 864 | 20′ |
| 50′ | 254 | .85866 | 691 | 753 | 10′ |
| **31°** | .51504 | .85717 | .60086 | 1.6643 | **59°** |
| 10′ | 763 | 567 | 483 | 534 | 50′ |
| 20′ | .52002 | 416 | 881 | 426 | 40′ |
| 30′ | 250 | 264 | .61280 | 319 | 30′ |
| 40′ | 498 | 112 | 681 | 212 | 20′ |
| 50′ | 745 | .84959 | .62083 | 107 | 10′ |
| **32°** | .52992 | .84805 | .62487 | 1.6003 | **58°** |
| 10′ | .53238 | 650 | 892 | 5900 | 50′ |
| 20′ | 484 | 495 | .63299 | 798 | 40′ |
| 30′ | 730 | 339 | 707 | 697 | 30′ |
| 40′ | 975 | 182 | .64117 | 597 | 20′ |
| 50′ | .54220 | 025 | 528 | 497 | 10′ |
| **33°** | .54464 | .83867 | .64941 | 1.5399 | **57°** |
| 10′ | 708 | 708 | .65355 | 301 | 50′ |
| 20′ | 951 | 549 | 771 | 204 | 40′ |
| 30′ | .55194 | 389 | .66189 | 108 | 30′ |
| 40′ | 436 | 228 | 608 | 013 | 20′ |
| 50′ | 678 | 066 | .67028 | 4919 | 10′ |
| **34°** | .55919 | .82904 | .67451 | 1.4826 | **56°** |
| 10′ | .56160 | 741 | 875 | 733 | 50′ |
| 20′ | 401 | 577 | .68301 | 641 | 40′ |
| 30′ | 641 | 413 | 728 | 550 | 30′ |
| 40′ | 880 | 248 | .69157 | 460 | 20′ |
| 50′ | .57119 | 082 | 588 | 370 | 10′ |
| **35°** | .57358 | .81915 | .70021 | 1.4281 | **55°** |
| 10′ | 596 | 748 | 455 | 193 | 50′ |
| 20′ | 833 | 580 | 891 | 106 | 40′ |
| 30′ | .58070 | 412 | .71329 | 019 | 30′ |
| 40′ | 307 | 242 | 769 | .3934 | 20′ |
| 50′ | 543 | 072 | .72211 | 848 | 10′ |
| **36°** | .58779 | .80902 | .72654 | 1.3764 | **54°** |
| 10′ | .59014 | 730 | .73100 | 680 | 50′ |
| 20′ | 248 | 558 | 547 | 597 | 40′ |
| 30′ | 482 | 386 | 996 | 514 | 30′ |
| 40′ | 716 | 212 | .74447 | 432 | 20′ |
| 50′ | 949 | 038 | 900 | 351 | 10′ |
| **37°** | .60182 | .79864 | .75355 | 1.3270 | **53°** |
| 10′ | 414 | 688 | 812 | 190 | 50′ |
| 20′ | 645 | 512 | .76272 | 111 | 40′ |
| 30′ | 876 | 335 | 733 | 032 | 30′ |
| 40′ | .61107 | 158 | .77196 | .2954 | 20′ |
| 50′ | 337 | .78980 | 661 | 876 | 10′ |
| | cos | sin | cot | tan | |

## 38° to 45°

| | sin | cos | tan | cot | |
|---|---|---|---|---|---|
| **38°** | .61566 | .78801 | .78129 | 1.2799 | **52°** |
| 10′ | 795 | 622 | 598 | 723 | 50′ |
| 20′ | .62024 | 442 | .79070 | 647 | 40′ |
| 30′ | 251 | 261 | 544 | 572 | 30′ |
| 40′ | 479 | 079 | .80020 | 497 | 20′ |
| 50′ | 706 | .77897 | 498 | 423 | 10′ |
| **39°** | .62932 | .77715 | .80978 | 1.2349 | **51°** |
| 10′ | .63158 | 531 | .81461 | 276 | 50′ |
| 20′ | 383 | 347 | 946 | 203 | 40′ |
| 30′ | 608 | 162 | .82434 | 131 | 30′ |
| 40′ | 832 | .76977 | 923 | 059 | 20′ |
| 50′ | .64056 | 791 | .83415 | .1988 | 10′ |
| **40°** | .64279 | .76604 | .83910 | 1.1918 | **50°** |
| 10′ | 501 | 417 | .84407 | 847 | 50′ |
| 20′ | 723 | 229 | 906 | 778 | 40′ |
| 30′ | 945 | 041 | .85408 | 708 | 30′ |
| 40′ | .65166 | .75851 | 912 | 640 | 20′ |
| 50′ | 386 | 661 | .86419 | 571 | 10′ |
| **41°** | .65606 | .75471 | .86929 | 1.1504 | **49°** |
| 10′ | 825 | 280 | .87441 | 436 | 50′ |
| 20′ | .66044 | 088 | 955 | 369 | 40′ |
| 30′ | 262 | .74896 | .88473 | 303 | 30′ |
| 40′ | 480 | 703 | 992 | 237 | 20′ |
| 50′ | 697 | 509 | .89515 | 171 | 10′ |
| **42°** | .66913 | .74314 | .90040 | 1.1106 | **48°** |
| 10′ | .67129 | 120 | 569 | 1041 | 50′ |
| 20′ | 344 | .73924 | .91099 | 977 | 40′ |
| 30′ | 559 | 728 | 633 | 913 | 30′ |
| 40′ | 773 | 531 | .92170 | 850 | 20′ |
| 50′ | 987 | 333 | 709 | 786 | 10′ |
| **43°** | .68200 | .73135 | .93252 | 1.0724 | **47°** |
| 10′ | 412 | .72937 | 707 | 661 | 50′ |
| 20′ | 624 | 737 | .94345 | 599 | 40′ |
| 30′ | 835 | 537 | 896 | 538 | 30′ |
| 40′ | .69046 | 337 | .95451 | 477 | 20′ |
| 50′ | 256 | 136 | .96008 | 416 | 10′ |
| **44°** | .69466 | .71934 | .96569 | 1.0355 | **46°** |
| 10′ | 675 | 732 | .97133 | 295 | 50′ |
| 20′ | 883 | 529 | 700 | 235 | 40′ |
| 30′ | .70091 | 325 | .98270 | 176 | 30′ |
| 40′ | 298 | 121 | 843 | 117 | 20′ |
| 50′ | 505 | .70916 | .99420 | 058 | 10′ |
| **45°** | .70711 | .70711 | 1.00000 | 1.0000 | **45°** |
| | cos | sin | cot | tan | |

## 53° to 60°

## 45° to 52°

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